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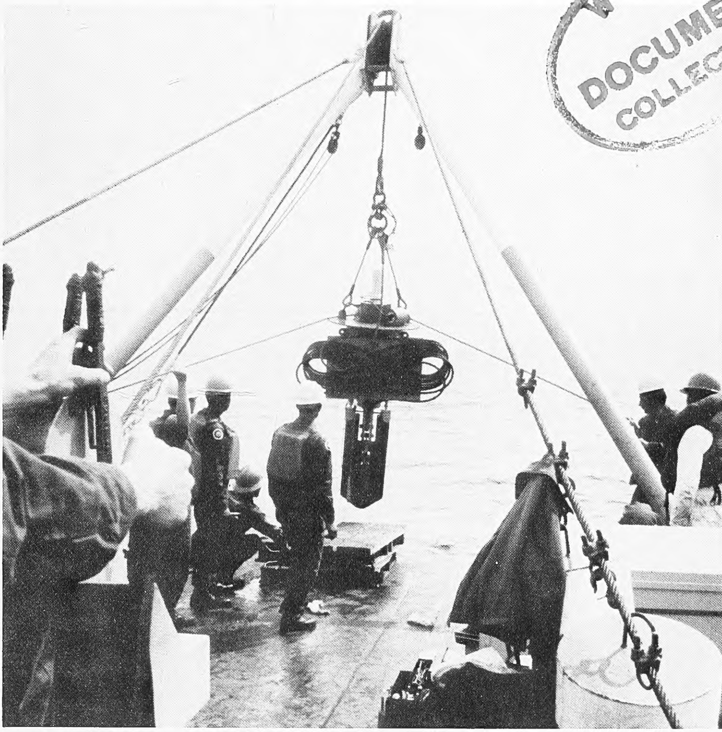

CEL 20K PROPELLANT-ACTUATED ANCHOR

by R. J. Taylor

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A propellant-actuated anchor (CEL 20K) has been designed to function in seafloors from soft clay to competent basalt, yielding a minimum long-term hodling capacity of 20,000 pounds in water depths of 50 to 20,000 feet. Thirty-six individual tests of the anchor are described in detail, demonstrating that the anchor functions satisfactorily in a wide variety of situations. Generalized and specific applications are given along with alternative installation and recovery schemes for the anchor.

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1. Propellant-actuated anchors 2. Moorings I. 3.1330-1

A propellant-actuated anchor (CEL 20K) has been designed to function in seafloors from soft clay to competent basalt, yielding a minimum long-term holding capacity of 20,000 pounds in water depths of 50 to 20,000 feet. Thirty-six individual tests of the anchor are described in detail, demonstrating that the anchor functions satisfactorily in a wide variety of situations. Generalized and specific applications are given along with alternative installation and recovery schemes for the anchor.

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INTRODUCTION

This report describes the development of the Civil Engineering Laboratory's (CEL) 20K propellant-actuated anchor (Deep-Water Anchor).* The project was sponsored by the Naval Facilities Engineering Command under the Naval Materiel Command's Deep Ocean Technology program. The anchor was designed to develop a minimum long-term holding capacity of 20,000 pounds in seafloors from soft clay to competent rock and to be operable in water depths from 50 to 20,000 feet. The results of the testing program used to define the anchor's performance in a variety of seafloor materials and in a range of water depths to 20,000 feet are given along with alternative installation and recovery schemes for the anchor.

A detailed study of existing and conceptualized anchors was undertaken to determine the most suitable and widely applicable anchor for deep-water operations. It was impractical to find an anchor that would efficiently satisfy every application, but it appeared that the propellant-actuated anchor offered the widest range of applications. Of particular significance were the propellant-actuated anchor's adaptability to variable seafloor conditions and its high anchoring efficiency.

The ordnance system for the 20K anchor was designed for CEL by the Naval Ordnance Station, Indian Head, Maryland, and the anchor safe-and-arm device was designed by the Naval Underwater Systems Center, Newport, Rhode Island. The remainder of the anchor system was designed and fabricated at CEL. Figure 1 is a view of the CEL 20K anchor as it is about to be placed over the bow of a Navy warping tug.

BACKGROUND

The propellant-actuated anchor concept advanced to the hardware stage in 1959. Since that time several propellant-actuated anchors have been developed by both government agencies and private industry.** Initial problems concerning structural and mechanical aspects have largely been overcome; anchor reliability, efficiency, safety, and simplicity have been advanced to the point where this anchor can be considered a viable alternative to conventional anchors.

Standard drag anchors behave poorly in rock, coral, cemented, or very dense seafloors; holding capacities are erratic or nonexistent. Anchor flukes will not key into any of these seafloors. Capacity is developed only through minimal friction or possible snagging on a rock outcrop. In contrast, the propellant-actuated anchor functions best in coral, cemented or very dense seafloors. Data on performance in rock are minimal, but results to date indicate that large capacities are possible.

In well-used harbors, channels, or any other confined area it can be impractical to lay the long scopes of chain or line on the seafloor required for standard drag anchors. These mooring legs can be disturbed by temporary ships' anchors and can effectively reduce ship operating area because the mooring legs rise close to the surface when in use. To avoid this, large clumps are normally attached to each leg to reduce chain scope, thereby resulting in a more difficult installation. Line scope is considerably reduced with propellant-actuated anchors, which can minimize the difficulties listed above.

* CEL now has three propellant-actuated anchors; to simplify their reference, their names are designated simply by their nominal long-term capacity in a soft seafloor sediment.

** See Reference 1 for more detail on these anchors.

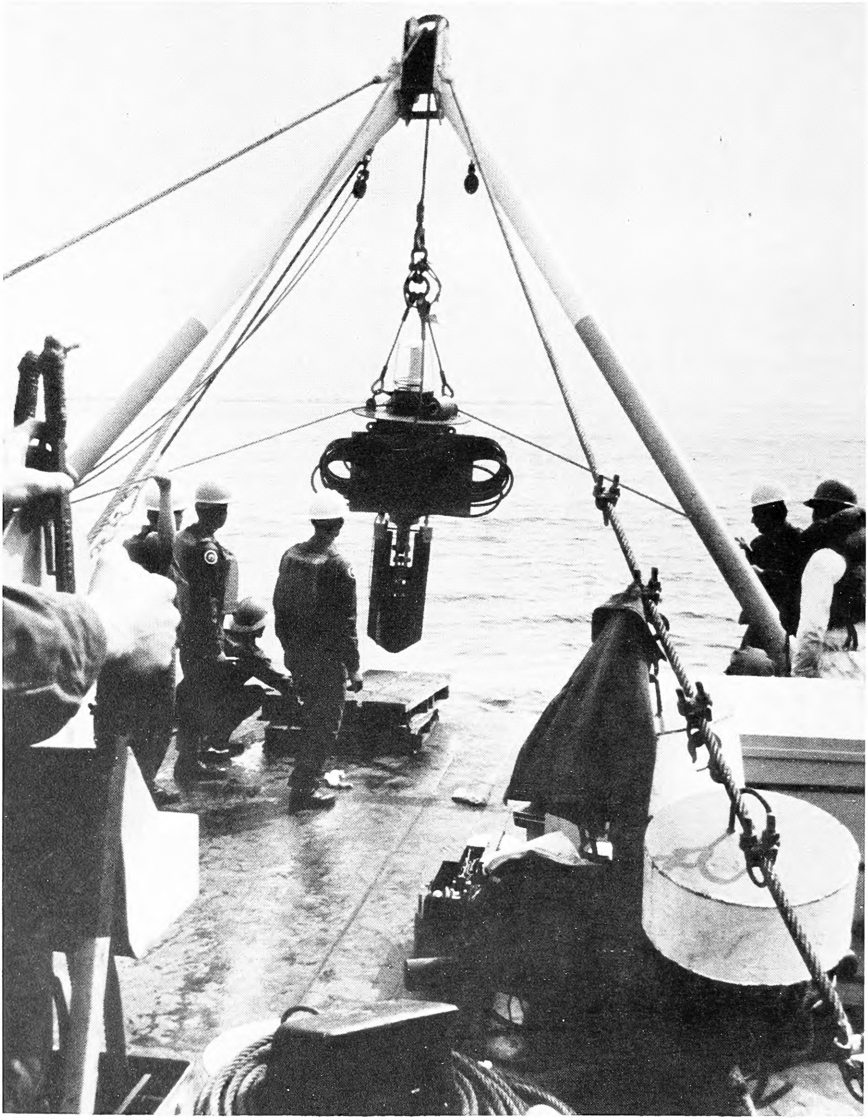


Figure 1. CEL 20K anchor being placed from a Navy warping tug.

The installation of conventional anchors in deep water is difficult and expensive. Horizontal loading of standard drag anchors is required for peak performance; this is accomplished with long scopes of line and/or deadweight to reduce line scope. Deadweight alone in deep water is practical for only very low capacities, that is, less than a few thousand pounds. Deadweight anchors with efficiencies as low as or lower than 0.3 require very large line sizes during position-controlled installation; also, the equipment necessary to handle these large anchors and long lengths of chain and line is not standard equipment on most vessels. The high efficiencies of propellant-actuated anchors and their capability of resisting uplift loads eliminate the requirements for long scopes of line and lines larger than those required for the actual in-service loads.

In summary, the advantages of the propellant -actuated anchor are: Simplified handling; the ability to resist multidirectional loads; speed of emplacement; reduction in line scope and use of connective apparatus, particularly in deep water; accuracy of placement, ability to embed without dragging, and functionability on moderate slopes and in lithified sediments.

The CEL 20K anchor can be utilized in practically any situation in which a conventional anchor can be used. In those situations where installation time and weight of the mooring system must be minimized and where the ability to resist uplift loads is required, the CEL 20K anchor provides a practical alternative to conventional anchors. One of the prime potential uses for the 20K anchor is for mooring instrument arrays. Small diameter cables are needed in these arrays to minimize current effects; this, coupled with desired high line tensions, leads one to use highly efficient anchors.

The CEL 20K anchor was recently used by CEL to anchor the SEACON II experimental tri-moor cabled structure (Figure 2), which is configured and instrumented to obtain response measurements of an internally redundant three-dimensional cable structure to ocean currents; implant water depth was 2,900 feet.* Two 20K anchors and one clump moored the main structure, and one 20K anchor secured a construction buoy.

The anchors for the structure were proof-tested to 15,000 pounds, but the actual in-service loads have been only a few thousand pounds. The anchors have resisted these loads with no problem. The construction moor requirements, however, were significantly greater. The primary function of the construction moor was to stabilize and restrain the CEL warping tug during array installation and monitoring. The anchor was proof-tested to over 25,000 pounds, and at one point, in-service loads of 15,000 to 20,000 pounds were exerted on the anchor by a moored vessel for about 16 hours during storm conditions. As of this report, SEACON has been in-place for about one year, and the moor anchor has successfully held all loadings applied to it.

The CEL 100K anchor (Launched Penetrating Salvage Anchor) [3] was designed to provide reaction for ATF and ARS class vessels that are pulling stranded ships free. In those cases where the 100K anchor is unavailable or where the ship's handling capability is insufficient, the CEL 20K anchor could be used as long as it was limited to coral, sand, and possibly rock seafloors; clay/mud seafloors should be excluded due to their lower capacity. The 100K anchor will withstand loads over 200,000 pounds in the more competent seafloors as compared to 60,000 to 80,000 pounds for a CEL 20K anchor with a larger cable attached to the sand fluke. Since the beach gear leg typically used in salvage operations is designed to pull 80,000 pounds [4], the CEL 20K anchor could be suitable if it were used in the combination shown in Figure 3.

The CEL 20K anchor could also be used to moor data acquisition buoys such as the NOAA monster buoys, research vessels, and small tankers moored short-term. Single-point and multipoint ship moors, TOTO I, TOTO II and HARDTACK, and the subsurface submarine target SQUAW [5] are excellent examples of systems whose installations could be simplified by the use of propellant-actuated anchors. Although propellant-actuated anchors were not suitably developed at the time of these installations, this type of anchor would have reduced the number of ships required, eliminated the need for heavy gear to handle deadweights to 25,000 pounds, and reduced the number of mooring legs due to its multidirectional holding capability.

* See Reference 2 for SEACON II details.

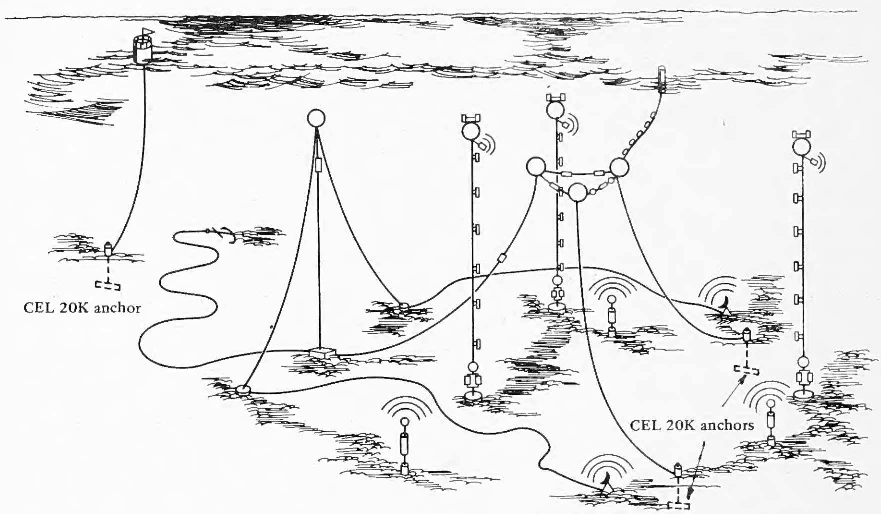


Figure 2. SEACON II experimental cabled structure.

DESCRIPTION OF EQUIPMENT

The CEL 20K anchor, whose design was detailed in Reference 6, is comprised of two principal parts: the fluke assembly and the gun assembly. Figure 4 shows the anchor in its cradle in the position normally used for assembling the anchor. The basic anchor stands about 7 feet high and weighs 1,800 to 2,000 pounds, depending upon which fluke is used. Two fluke configurations were necessary to satisfy the anticipated seafloor types; one for sediments and one for rock and coral. Three sediment flukes are currently used to obtain peak performance in seafloor soils. The physical dimensions of the four anchor assemblies are detailed in Table 1.

Functional Description

The anchor can be installed in a variety of ways (see Appendix B, Installation and Recovery Methods); however, the functioning of the anchor remains basically the same (Figure 5). Above 50 feet the anchor is prevented from activating by a switch and a plunger that are both hydrostatically controlled. Anchor embedment is initiated when a probe senses the seafloor. The fluke assembly (fluke/piston) is restrained by shear pin links until the gun barrel pressure equals 3,000 psi. At this point, the fluke assembly is propelled into the seafloor at velocities up to 400 ft/sec while dragging the flaked downhaul cable into the seafloor. The fluke can be set if necessary, and the launch vehicle can be retrieved for reuse or discarded, depending upon operational requirements.

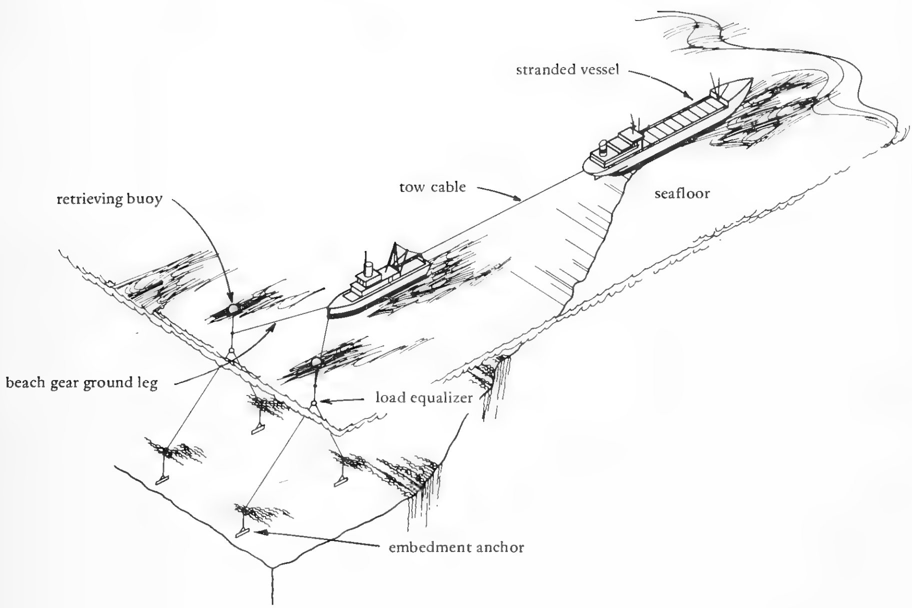


Figure 3. CEL 20K anchor; salvage usage in competent seafloors.

Major Components

Sediment Fluke Assemblies. Three flukes are used to optimize performance in seafloor sediments: one for sand and stiff clay (1-1/2 x 3 feet), one for sand and medium stiff clay (2 x 4 feet), and one for soft clay (2-1/2 x 5 feet). The fluke sizes and shapes were devised through theoretical and experimental investigations [6]. Their characteristics are detailed in Table 2.

All sediment flukes are of bent plate configuration with nominal length to width ratios of 2. They are designed to key or rotate rapidly from the vertical to the horizontal position when an uplift force through the anchor downhaul cable (pendant) is applied after completion of penetration. The keying action illustrated in Figure 6 occurs in a vertical distance of 1-3/4 x fluke length, measured from the fluke tip. Figure 7 shows a sand fluke assembly in its penetrating position and in its keyed position. There is no rigid mechanical connection at the point of contact between the fluke and piston; during penetration, these components maintain contact through a combination of inertial and drag forces.

Rock Fluke Assembly. The rock fluke assembly consists of a fluke and piston; its characteristics are listed in Table 2 and illustrated in Figure 8. The original design [6] utilized a three-fin arrowhead configuration consisting of 100 ksi 4140 steel for the plates and central shaft and a 4340 hardened steel nose. The existing fluke has been modified slightly. The nose is no longer threaded to the central shaft; the shaft and nose are now one piece and is fabricated from 4140 steel. The main fluke plates are welded at 180 degrees rather than the original 140 degrees included angle.

Table 1. Physical Dimensions of CEL 20K Anchor Assemblies

Item	Anchor Assembly With –			
	Sand Fluke	2 x 4-Foot Clay Fluke	2-1/2 x 5-Foot Clay Fluke	Rock Fluke
Length (ft)	7	8	9	7
Diameter (ft)	2	2	2-1/2	2
Nominal weight (lb)				
Gun assembly	1,500	1,500	1,500	1,500
Fluke assembly	300	370	490	300
Total weight (lb)	1,800	1,870	1,990	1,800
Downhaul cable				
Length (ft)	75	100	100	10
Type	6 x 19 IWRC	6 x 19 IWRC	6 x 19 IWRC	6 x 19 Fibercore
Diameter (in.)	7/8	3/4	3/4	1
Breaking strength (lb)	80,000	59,000	59,000	89,000

Table 2. Characteristics of Anchor Fluke Assembly

Characteristic	Sand Fluke	2 x 4-Foot Clay Fluke	2-1/2 x 5-Foot Clay Fluke	Rock Fluke
Length (in.)	38	51	63	36
Width (in.)	18	24	30	18
Thickness (in.)	1/2	1/2	1/2	1
Plan area (sq ft)	4.5	8.0	12.5	–
Fluke weight (lb)	147	217	337	160
Material type	A514 or A517 steel	A514 or A517 steel	A514 or A517 steel	4140 steel
Piston weight (lb)	116	116	116	115
Piston extension weight (lb)	24	24	24	–
Connective gear weight (lb)	13	13	13	25

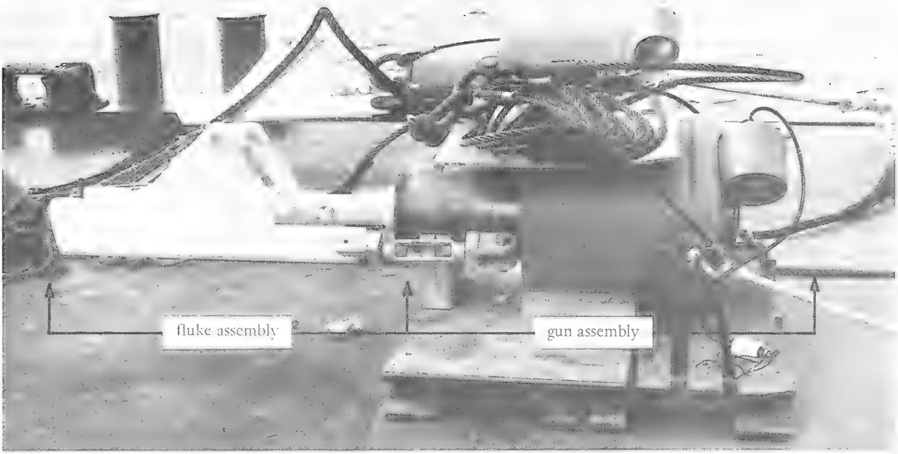


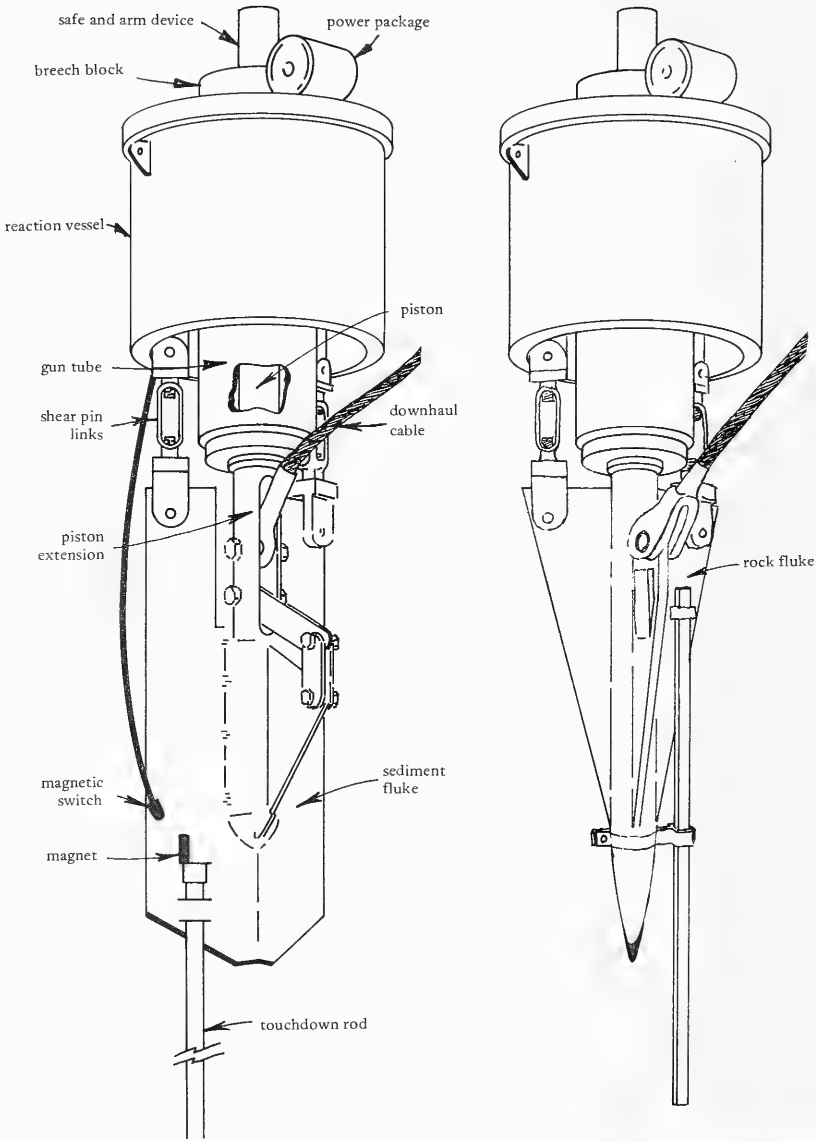
Figure 4. CEL 20K anchor in position for on-deck assembly.

Gun Assembly. Included in the gun assembly are the reaction vessel, gun, and cartridge assembly. The reaction vessel is composed of a threaded 2-1/2-inch-thick steel plate that is welded to a 20-inch-diameter schedule 120 steel pipe. A used surplus Army 90-mm M41 gun tube that has been shortened and smooth-bored is used to reduce system cost and to allow system expendability if required. The reaction vessel is attached to the gun tube by threading it on the existing gun tube threads. A breechblock machined from 160 ksi 4340 steel was designed to match the existing gun threads. Recoil height of the basic system was not considered a critical problem; therefore, a large drag area was not employed. However, this is easily rectified if shallow water use is needed. A 3-foot-diameter, 1/2-inch-thick A514 steel plate was placed on the reaction vessel for tests recently performed in 45 feet of water (Figure 9). Reaction distance was reduced from about 30 feet to 12 to 15 feet.

The cartridge assembly (Figure 10) consists of the following:

Army M108B1 cartridge case . .	Shortened to 10 in.
M58 primer	Shortened & reduced charge
Navy smokeless propellant . . .	PYRO
Obturator plug	Polyethylene disk
Wadding	Styrofoam

The obturator plug holds the propellant in place and also seals the gas behind the piston, which extends into the tapered cartridge chamber of the M41 gun tube. Figure 11 shows the gun and cartridge assembled for use.



(a) Anchor with sediment fluke.

(b) Anchor with rock fluke.

Figure 5. Schematics of the CEL 20K anchor.

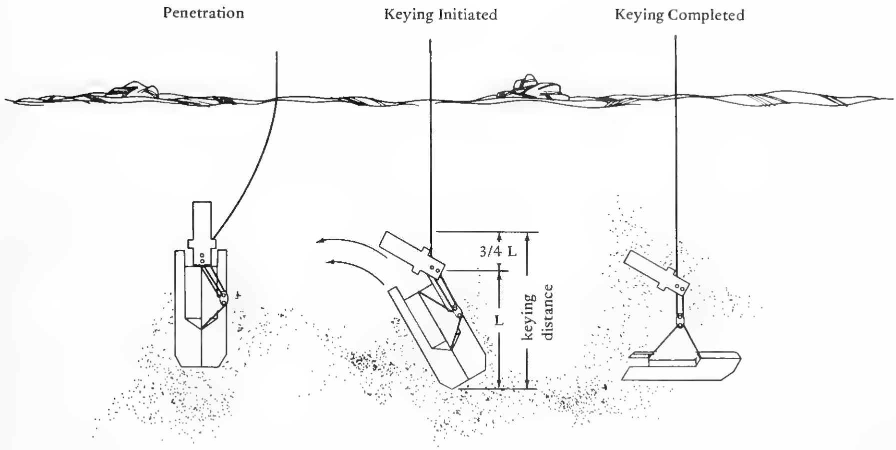
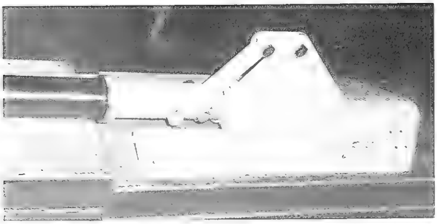


Figure 6. Keying position for sediment fluke.

The Naval Ordnance Station, Indian Head, Maryland, determined that standard Navy pyrotechnic propellant would provide acceptable performance over a broad depth range. With the propellant type and the characteristics of the gun assembly known, CEL could determine, using an NOS-developed interior ballistics computer simulation, the most suitable grain configuration and charge weights for the various anchor projectiles and water depths. The result of the effort indicated that PYRO with a 0.08-inch web thickness (material thickness between perforations) would yield a balance between the performance of the small and large projectiles. During the anchor test program a more readily available PYRO, 0.074-inch web thickness (typically used in the Navy 6-inch gun), was used. It would be suitable for most anchor applications; performance actually differs only slightly from the 0.08-inch web PYRO.

The performance of each anchor projectile using the 0.074-inch web PYRO is illustrated in Figure 12. The maximum charge weight that can be used is limited by either a 35,000-psi gun barrel pressure or 3.75 pounds (cartridge limit). Peak performance for these projectiles with 0.074-inch web PYRO is obtained by using these limiting criteria to determine necessary charge weights; these data are summarized in Figure 13.

Firing Mechanism. The firing mechanism (Figure 14) consists of a weighted touchdown rod, a power supply, and a safe-and-arm (S/A) device. The touchdown rod extends 26 inches below the fluke top and is weighted in such away that it will slide relative to the fluke when its 1-1/2-inch-square base contacts 1/4-psi shear strength soil or greater. It will not move in the water column up to lowering velocities of 17 ft/sec, which is a reasonable safety margin above its intended maximum of 2 ft/sec.



(a) Penetrating position.

(b) Keyed position.

Figure 7. Sediment fluke for CEL 20K anchor.

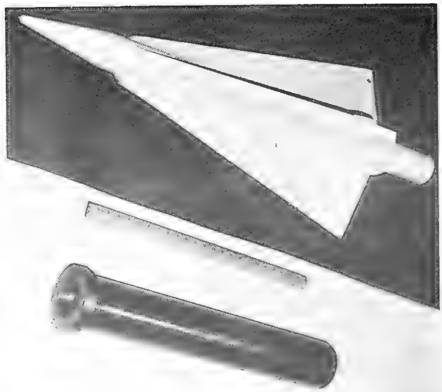


Figure 8. Rock fluke assembly for CEL 20K anchor.

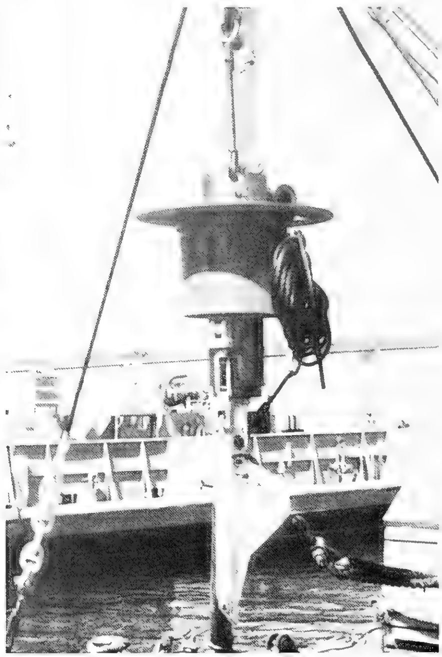


Figure 9. CEL 20K anchor with reaction plate added for shallow-water usage.

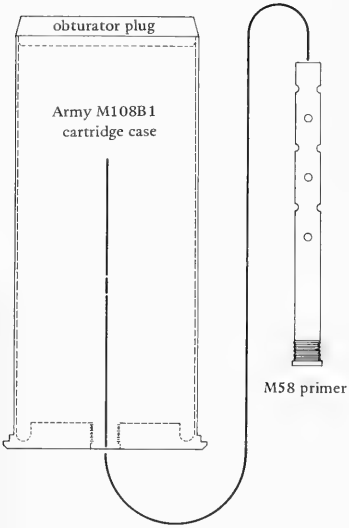


Figure 10. Cartridge assembly for CEL 20K anchor.

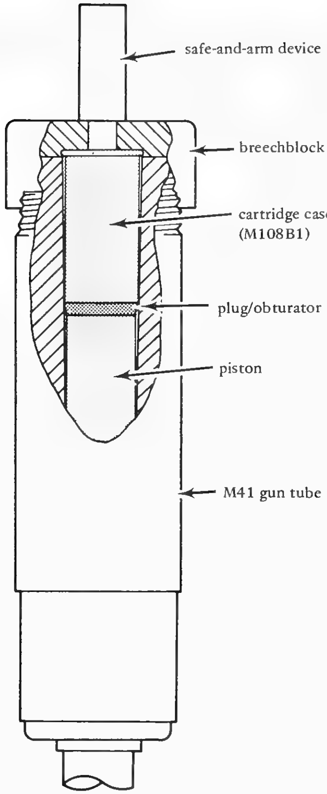
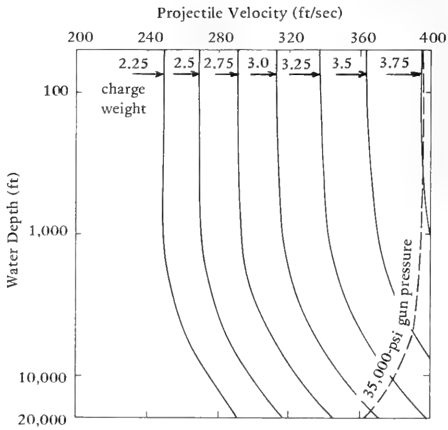


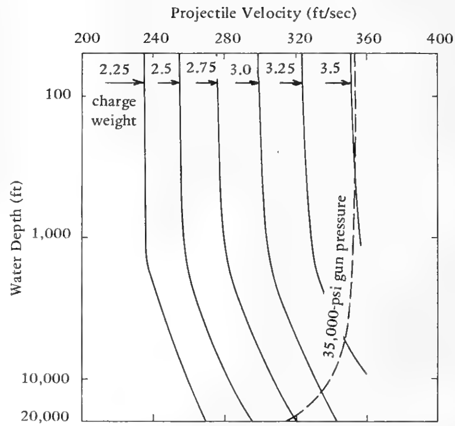
Figure 11. Gun and cartridge assembly for CEL 20K anchor.

Functionally, as the rod touches the seafloor, the magnet located on the rod approaches the magnetic switch, which is fixed relative to the fluke, and momentarily closes it. The power source then activates the S/A device which in turn detonates the cartridge. Above 50 feet firing is prevented by a hydrostatic pressure switch that interrupts the nickel cadmium battery power source, and by a hydrostatically activated mechanical interlock that prevents motion of a firing pin in the S/A. Below 50 feet, upon touchdown, the power source activates a valving assembly that completes a gas flow path to the firing pin and releases the 1,100-psi nitrogen; this action then causes a 400-psi shear disk above the firing pin to rupture. After rupture, the pressure drives a firing pin either into a detonator for the ordnance S/A or directly into the M58 primer for the nonordnance reusable S/A.

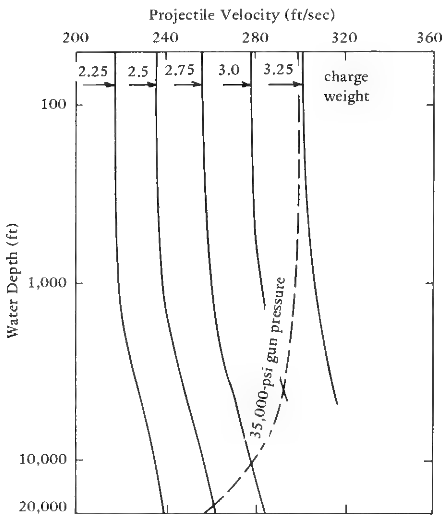
The original S/A device is shown in Figure 15. The base section of the S/A device, which was adapted from the Navy Signal Underwater Sound (SUS) charge, worked perfectly; however, problems were encountered with sealing the 1,100-psi nitrogen. The inflator was not a satisfactory means for sealing



(a) 300-pound, 1-1/2 x 3-foot sand fluke or rock fluke.



(b) 370-pound, 2 x 4-foot clay fluke.



(c) 490-pound, 2-1/2 x 5-foot clay fluke.

Figure 12. Projectile velocity versus water depth for various charge weights using 0.074-inch web PYRO.

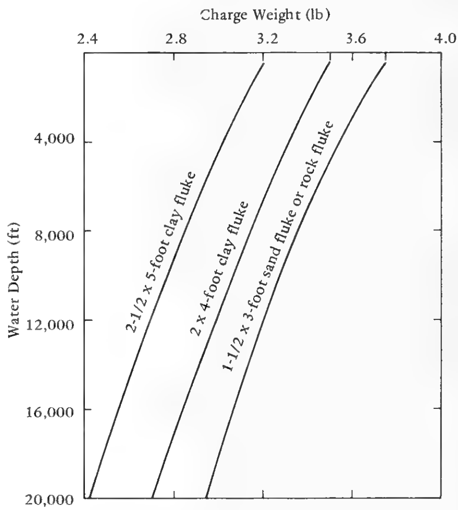


Figure 13. Charge weight versus water depth for peak gun performance using 0.074-inch web PYRO.

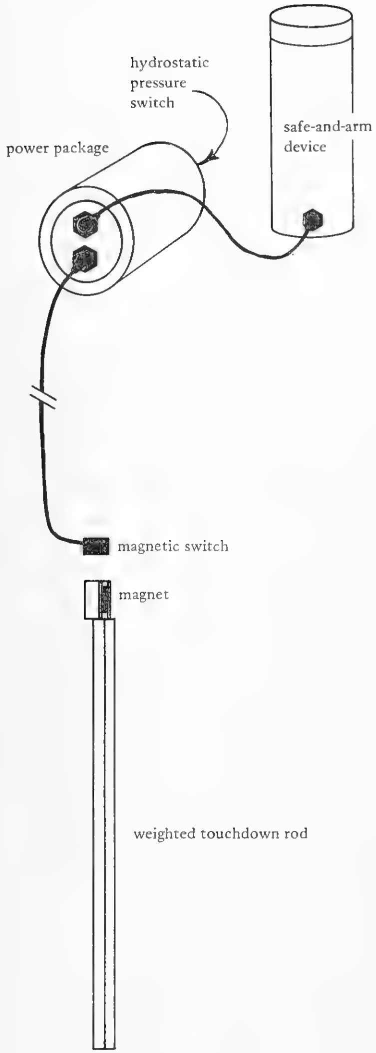


Figure 14. Firing mechanism for CEL 20K anchor.

the 1,100-psi nitrogen for extended periods of time. Also, when the gas bottle was punctured with the inflator, the small metal piece that sealed the bottle would pass into the solenoid valving assembly and cause the solenoids to leak. Thus, a successful bench firing of the assembly was not a suitable guarantee of success. These problems were eliminated by replacing the gas bottle/inflator assembly with a fabricated refillable gas canister with a one-way filling valve on top. The modified upper gas assembly is shown in Figure 16.

Other modifications were made to the gas assembly to improve reliability. The first involved combining the two solenoid valves into one body to shorten the unit and eliminate connective piping; the second involved the activation time phasing for the two valves. Originally, there was a 30-msec delay between the time the first (three-way) valve and the second (two-way) valve were activated. This was to ensure that the three-way valve was closed to the S/A chamber and open to the shear disk prior to activating the two-way valve and releasing the nitrogen pressure. Additional testing showed this delay, which was provided by an electronic circuit in the power package, to be unnecessary. This change most likely occurred because of the larger volume of gas stored in the reusable gas canister as compared to the throw-away gas bottle previously used.

The ordnance S/A assembly did create a problem during the testing phase that would be of no concern if the system were totally expended. The S/A base would expand during firing, making retraction extremely difficult. To eliminate this problem and also to reduce cost and simplify operations in shallow water where the gun assembly is recovered and refurbished, a new nonordnance S/A was developed (Figure 17). The system costs 20% more than the ordnance S/A, but it can be used 20 to 30 times before the aluminum housing is worn. Stainless steel components could increase its use even further. As mentioned, the firing pin directly detonates the M58 primer in the cartridge. Above 50 feet, the pin is mechanically blocked by the hydrostatically activated plunger.

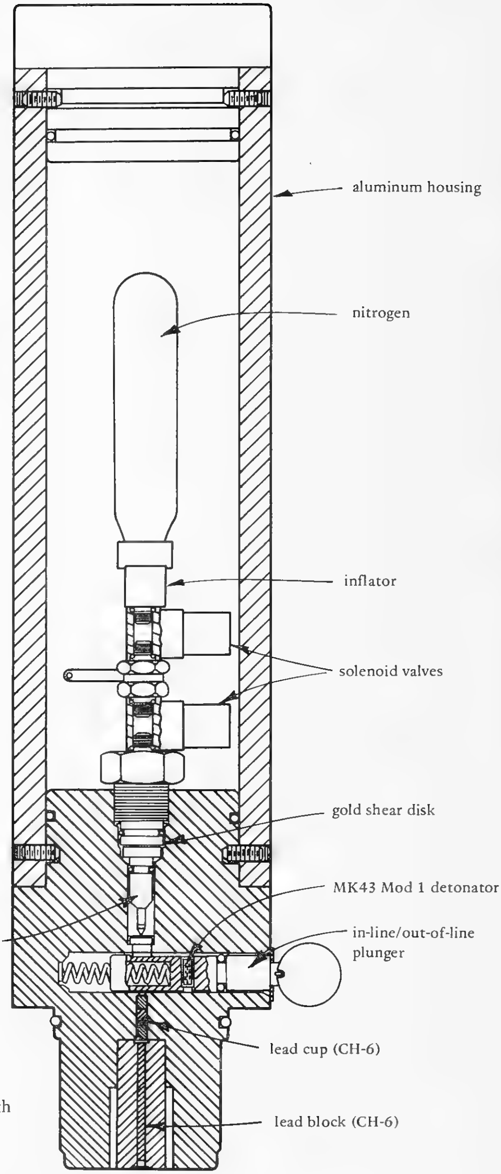


Figure 15. Ordnance safe-and-arm device with gas bottle/inflator assembly.

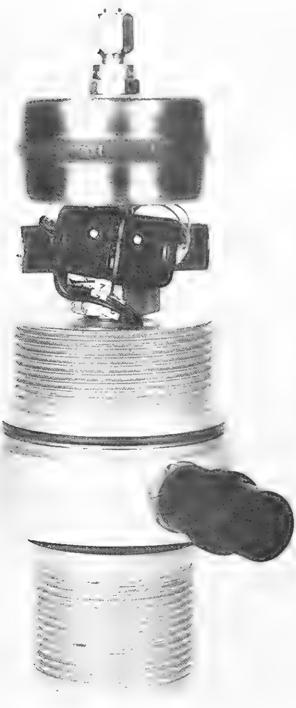


Figure 16. Ordnance safe-and-arm device with refillable gas canister assembly.

TEST PROGRAMS AND PROCEDURES

The anchor was thoroughly tested on land to define gun system performance.* The ballastic performance was in excellent agreement with predicted performance. Subsequent to this evaluation, the 20K anchor was either tested or utilized 36 times in a wide range of water depths and seafloor conditions. The intent was not to try to thoroughly evaluate anchor performance under every conceivable situation (because this would be economically impractical), but simply to show that the system functions in a wide variety of situations. In addition to the actual testing of the anchor, attempts were and are continually being made to use the anchor in actual field installations, such as the SEACON II installation and an amphibious operation off San Diego, to gather reliability data.

Test procedures for the anchor varied somewhat, depending upon the test objectives, test vessel, and water depth; however, a generalized procedure can be described. This procedure is detailed in an operations manual by Taylor and Babineau [7]. The anchor is partially assembled, the launch vehicle and gun are connected, and this package is placed in its cradle where the fluke assembly, cable, cartridge, and firing mechanism are installed and checked. The anchor is then picked up, placed over the side, and lowered to the seafloor at up to 300 ft/min. After the anchor has fired and embedded, a load cell is attached to the main load line unless the line runs over a mechanical or electrical dynamometer. Load is applied slowly by winch or ship's power, and a continuous trace of pullout load is obtained. Normally, penetration depth is also recorded, and, in a few cases, load displacement records are obtained. These generally depend upon the resolution of the ship's depth recording instrumentation. A pinger is placed a known distance above the gun assembly. When load is applied to the anchor load line after the anchor has been fired, the depth of penetration can be determined within a couple of feet. The pinger sends a direct and an indirect (to the seafloor and then to the ship) signal. The length of line between the pinger and the fluke minus the distance of the pinger above the seafloor yields the fluke embedment depth.

Soils data were always obtained at each site. The amount and type of data depended greatly upon water depth, ship's capability, weather conditions, and available test time. In some cases, charts and other documents indicating the general nature of the site were all that could be obtained. However, near Port Hueneme, tests were performed at established sites where considerable in-situ and laboratory data were available. Generally, the level of knowledge about a site is derived from data taken from the literature, a short core, and sediment taken off the fluke (assumed to be from the deepest penetration).

* The results of the test program are summarized in Reference 6.

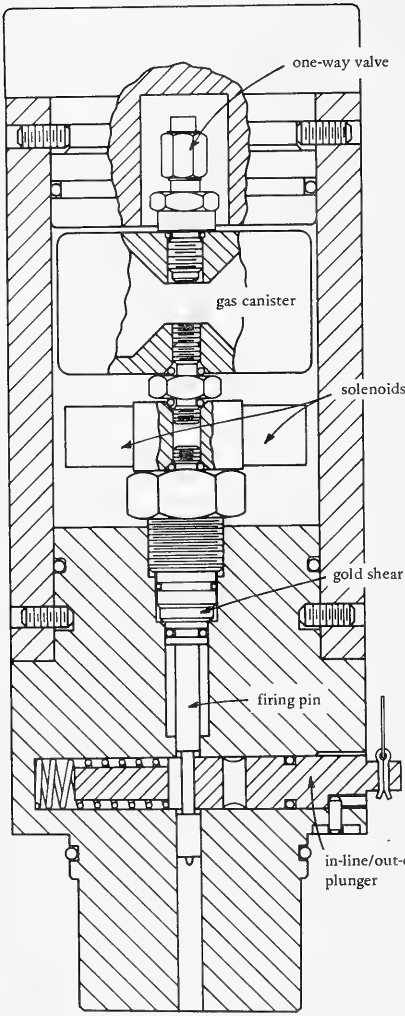


Figure 17. Nonordnance, reusable safe-and-arm device (S/A) for CEL 20K anchor.

TEST RESULTS

A summary of all test data derived during this development is provided in Table 3. This table includes general site information, gun performance holding capacity, and penetration data where available. Holding capacity is subdivided into pullout and no pullout. No pullout means that either the anchor line (downhaul cable) parted before pullout (Test 17), the anchors were used in an actual installation and just proof-tested (Tests 24 to 26), or the ship was incapable of pulling the anchors free (Tests 35 and 36). The last two tests were part of an amphibious operation, and load-measuring equipment was unavailable. During the initial stages of testing reduced propellant charges were used until it was determined that gun pressures were close to those predicted and that the fluke, which was not dynamically tested on land, was actually penetrating correctly and was structurally sound. Test 11 was the first time a peak charge was used.

Sediment Tests

Even though the data are somewhat limited, it is sufficient to generally show that the anchor does work. As expected, the largest holding capacities were recorded in silty sand, sand, and stiff clay, with the lowest in soft clay. The capacities in sands were actually somewhat higher than expected; this has resulted in a larger downhaul cable (7/8-inch diameter vice 3/4-inch diameter) to fully utilize fluke capabilities in this medium. This larger cable was used during tests 35-36, and the anchors could not be dislodged from a sand seafloor. The loads, though unmeasured, must have been considerable, because the impetus of a Navy warping tug was used to generate the pullout force. Tests 1, 3, and 17 illustrate the high capacities that can be achieved in a silty sand seafloor. Tests 1 and 3 were with reduced charges (peak gun pressures were 17 and 23 ksi, respectively), while test 17 used the maximum design charge (peak pressure was 35 ksi). The anchor fluke for test 17 was not pulled out prior to parting the wire.

Table 3. Test Data Summary of CEL 20K Anchor

(See Appendix A for details on each Test)

Operation	Test No.	Site	Date of Installation	Geographic Location	Water Depth (ft)	Subbottom Composition		Fluke Type (ft)	Charge Weight (lb)	Actual/Predicted Gun Barrel Pressure (ksi)	Penetration Depth (ft)		Projectile Velocity (ft/sec)	Holding Capacity (kips)		Comments
						Type of Soil	%				Before Keying	After Keying		Pullout	No Pullout	
I	1	Hueneme Canyon	6 Dec 1972	34° 6' 30" N 119° 16' W	110	Sand Silt Clay	62 32 6	1-1/2 x 3 (sand)	2.75	16.70/17.20	12.5	7.5*	290	42		1. Applied load in increments of 10 kips. 2. Reduced charge used (3.75 lb is max). 3. No damage to equipment.
	2	Hueneme Canyon	6 Dec 1972	34° 6' 30" N 119° 16' W	110	Silty sand		1-1/2 x 3 (sand)	3.25		no fire					1. System did not fire. 2. Originally attributed to hydrostatic switch; subsequent tests indicate failure attributed to magnetic touchdown assembly.
	3	Hueneme Canyon	7 Dec 1972	34° 6' 30" N 119° 16' W	110	Sand Silt Clay	70 26 4	1-1/2 x 3 (sand)	3.25	22.30/24.50	16-18	11-13*	335	48		1. Recoil of gun assembly measured 18 to 26 feet. 2. Reduced charge, but larger than test 1 (3.7 lb is max). 3. No damage to equipment.
II	4-5	SEACON I, Santa Barbara Channel	6 Feb 1973	34° 17' 12" N 119°42'47"W	600	Sand Silt Clay	20 64 16	1-1/2 x 3 (sand)	2.50		no fire					1. System did not fire. 2. Magnetic touchdown assembly redesigned to enhance magnetic field and assure triggering of the magnetic switch.
	6	SEACON I, Santa Barbara Channel	7 Feb 1973	34°17'12"N 119°42'47"W	550	Sand Silt Clay	20 64 16	1-1/2 x 3 (sand)	2.50	16.60/14.50	not measured		270	0		1. Test attempted without keying linkage; wire attached directly to fluke. 2. Piston did not rotate out of receptacle; keying did not occur. 3. No damage to equipment.
	7	900-ft site, Santa Barbara Channel	7 Feb 1973	34°19'0"N 119°49'0"W	900	Sand Silt Clay	8 48 44	1-1/2 x 3 (sand)	3.25	–/25.80	47*	42	345	20		1. Reduced charge used (3.7 lb is max). 2. Ship drifted from desired 600-foot site to 900-foot site where soil was softer; a larger fluke would have been appropriate. 3. No damage to equipment.
	8	1,200-ft site, Santa Barbara Channel	7 Feb 1973	34°16'30"N 119°50'8"W	1,200	Sand Silt Clay	4 46 50	2-1/2 x 5 (clay)	2.75	27.10/26.60	40*	32	260	17-40		1. Reduced charge used (3 lb is max). 2. First test with the 2-1/2 x 5-ft clay fluke. 3. 17 kips measured, but actual load estimated to be much higher. 4. Slack taken out of line before load cell hookup. Winch was actually stalled by mistake, required a stalling load in excess of 30 kips; load record indicated 10 kips additional for swell. 5. No damage to equipment.
	9	SEACON II, Santa Barbara Basin	8 Feb 1973	33°44'N 119°03'W	3,000	Sand Silt Clay	50 32 18	1-1/2 x 3 (sand)	3.25	26.90/26.80	23*	18	350	36		1. Reduced charge used (3.6 lb is max). 2. Anchor loaded slowly to 36 kips; ship then reversed direction and pulled the anchor out rapidly when the line became taut; this was not the desired test method. 3. No damage to equipment.
	10	SEACON II, Santa Barbara Basin	8 Feb 1973	33° 44'N 119°03'W	3,000	Sand Silt Clay	16 53 31	2 x 4 (clay)	2.75	–/24.80	30*	23	285	27		1. Reduced charge used (3.3 lb is max). 2. Load applied very quickly; ship had difficulty in controlling rate of application. 3. No damage to equipment.

Continued

Table 3. Continued.

Operation	Test No.	Site	Date of Installation	Geographic Location	Water Depth (ft)	Subbottom Composition		Fluke Type (ft)	Charge Weight (lb)	Actual/Predicted Gun Barrel Pressure (ksi)	Penetration Depth (ft)		Projectile Velocity (ft/sec)	Holding Capacity (kips)		Comments
						Type of Soil	%				Before Keying	After Keying		Pullout	No Pullout	
III	11	North of Anacapa	26 Mar 1973	34°00'30"N 119°24'30"W	67	Basalt	100	3 (rock)	3.75	31.95/34.60	2.5	fluke does not key	395	107		1. Max charge used. 2. Load applied at 60 deg and 90 deg from horizontal. 3. Capacity was 107,000 lb in direct uplift. 4. Fluke tip was bent at connection to shaft.
	12	North of Anacapa	26 Mar 1973	34°00'30"N 119°24'30"W	67	Basalt	100	3 (rock)	3.75	32.80/34.60	7	fluke does not key	395	20		1. Max charge used. 2. Embedded in a 45-60-deg rock slope. 3. First 4 ft of penetrated rock was chipped off. 4. Fluke tip was bent at connection to shaft, fluke tip will no longer be a separate threaded attachment. The central shaft will be solid 4140 steel.
IV	13-15	Hawaii (Honolulu), Penguin Bank Area	26-28 Jun 1973	20°57'00"N 157°35'00"W	180-600	Coral		1-1/2 x 3 (sand)	3.75		no fire					1. System did not fire; inflator assemblies leaked, causing firing pressure to drop to less than 400 psi, which is the minimum pressure required. 2. Problem was not determined until after test operation, the inflator assembly has since been eliminated, and procedures to detect any form of leakage have been outlined.
	16	Hawaii (Honolulu), Penguin Bank Area	29 Jun 1973	20°55'00"N 158°05'00"W	10,000	Sediment		1-1/2 x 3 (sand)	2.75		no fire					1. System did not fire, same reason as for test 13-15. 2. No water leakage occurred at 10,000 feet.
V	17	Hueneme Canyon	4 Dec 1973	34°08'00"N 119°18'00"W	150	Silty sand		1-1/2 x 3 (sand)	3.75	–/34.60	20	15*	395		58	1. Max charge used. 2. Test marked first time a full charge was used with the small fluke. 3. Downhaul cable parted at its rated strength of 58 kips. 4. No damage to the gun assembly.
	18	1,200-ft site, Santa Barbara Basin	5 Dec 1973	34°16'30"N 119°50'50"W	1,200	Sand Silt Clay	4 46 50	2 x 4 (clay)	3.25	31.00/30.80	34	27*	333	20		1. Reduced charge used (3.45 lb is max). 2. No damage to equipment.
	19	1,200-ft site, Santa Barbara Basin	5 Dec 1973	34°16'30"N 119°50'50"W	1,200	Sand Silt Clay	4 46 50	2-1/2 x 5 (clay)	3.00	–/32.00	40	32*	285	19		1. Reduced charge used (3.1 lb is max). 2. Test attempted without keying linkage as with test 6. Indications were that fluke did not key until almost pulled out. 3. No damage to equipment.

Continued

Table 3. Continued.

Operation	Test No.	Site	Date of Installation	Geographic Location	Water Depth (ft)	Subbottom Composition		Fluke Type (ft)	Charge Weight (lb)	Actual/Predicted Gun Barrel Pressure (ksi)	Penetration Depth (ft)		Projectile Velocity (ft/sec)	Holding Capacity (kips)		Comments
						Type of Soil	%				Before Keying	After Keying		Pullout	No Pullout	
VI	20	Atlantic Ocean, Cheatham Annex, Virginia	20 Jul 1974	37°22'54"N 73°32'23"W	8,000	Soft clay		1-1/2 x 3 (sand)	3.20		no fire					1. System did not fire; magnetic switch was faulty.
	21	Atlantic Ocean, Cheatham Annex, Virginia	22 Jul 1974	37°21.7'N 73°32.8'W	8,000	Soft clay		1-1/2 x 3 (sand)	3.20	–/30.50	not measured		366	13		1. Test location (water depth 8,000 ft instead of 6,000 ft) was changed, resulting in slightly reduced charge (3.3 lb is max). 2. Larger fluke should have been used, but seafloor data were unavailable to aid in fluke selection.
	22	Atlantic Ocean, Cheatham Annex, Virginia	23 Jul 1974	37°21.6'N 73°34.2'W	8,000	Soft clay		2 x 4 (clay)	3.10	–/32.0	not measured		336	8		1. Downhaul cable was too short, and it was damaged when penetration exceeded expectation. Cable connections were damaged, resulting in premature connection failure. 2. Downhaul cable was lengthened for tests in soft clay subsequent to this operation.
	23	Atlantic Ocean, Cheatham Annex, Virginia	23 Jul 1974	35°44.7'N 73°11.8'W	12,200	Stiff clay		1-1/2 x 3 (sand)	3.20	–/40.00	not measured		365	40		1. No damage to equipment.
VII	24	SEACON II, Santa Barbara Basin	5 Aug 1974	33°44'45"N 119°03'20"W	2,630	Sand Silt Clay	50 32 18	1-1/2 x 3 (sand)	3.60	–/35.00	not measured		390		25	1. Anchor tested to 25 kips without pullout. 2. Anchor is in service as a construction moor.
	25	SEACON II, Santa Barbara Basin	5 Aug 1974	33°44'45"N 119°03'20"W	2,710	Sand Silt Clay	50 32 18	1-1/2 x 3 (sand)	3.25	–/27.00	30*	25	350		15	1. Reduced charge used (3.6 lb is max), load requirements of anchors did not require peak charges. 2. Anchors tested to 15 kips without pullout; anchors in service mooring a cabled structure.
	26	SEACON II, Santa Barbara Basin	5 Aug 1974	33°44'45"N 119°03'20"W	2,700	Sand Silt Clay	50 32 18	1-1/2 x 3 (sand)	3.25	–/27.00	30*	25	350		15	1. Reduced charge used (3.6 lb is max); load requirements of anchors did not require peak charges. 2. Anchors tested to 15 kips without pullout; anchors in service mooring a cabled structure.
VIII	27	Hawaii	23 Sep 1974	20°35'N 156°25'W	18,700	Silty sand		1-1/2 x 3 (sand)	2.75	–/25.00	not measured		340	17-24		1. Reduced charge used (2.95 lb is max); a weak link was placed in the downhaul cable to avoid lowering line damage, a larger charge was unnecessary. 2. Difficulty was experienced with load measurement due to ship's positioning problems; it was difficult to keep the line straight over the load measuring sheave assembly. 3. No damage to equipment.

Continued

Table 3. Continued.

Operation	Test No.	Site	Date of Installation	Geographic Location	Water Depth (ft)	Subbottom Composition: Type of Soil	Subbottom Composition: %	Fluke Type (ft)	Charge Weight (lb)	Actual/Predicted Gun Barrel Pressure (ksi)	Penetration Depth (ft): Before Keying	Penetration Depth (ft): After Keying	Projectile Velocity (ft/sec)	Holding Capacity (kips): Pullout	Holding Capacity (kips): No Pullout	Comments
IX	28	North of Anacapa	6 Dec 1974	34°00'30"N 119°24'30"W	60	Cemented rock conglomerate	100	3 (rock)	3.75	– 28.00	not measured		395			1. The open socket attached to the fluke was fractured apparently by the piston when it ejected prematurely. Future rock flukes will be modified to prevent this by welding the main plates at 180 deg vice 140 deg.
	29	North of Anacapa	6 Dec 1974	34°00'30"N 119°24'30"W	60	Cemented rock conglomerate	100	3 (rock)	3.75	–/28.00	not measured		395	30		1. Fluke embedded in an uneven seafloor with large, partially cemented boulders.
X	30	SEACON I, Santa Barbara Channel	25 Feb 1975	34°17'12"N 119°42'47"W	600	Sand Silt Clay	20 64 16	1-1/2 x 3 (sand)	3.60	32.00	not measured		380			1. The fluke linkage was fractured, the exact cause is undetermined.
	31	SEACON I, Santa Barbara Channel	25 Feb 1975	34°17'12"N 119°42'47"W	600	Sand Silt Clay	20 64 16	1-1/2 x 3 (sand)	3.60	[illegible]	24-26	20*	380	28		1. The anchor performed satisfactorily, however, a larger (2 x 4-ft) fluke could have been used for improved performance. Available soil data to 10 ft indicated a much higher strength soil at 20 ft, this trend was false. As a result, the small fluke was chosen. 2. No damage to equipment.
	32	SEACON I, Santa Barbara Channel	26 Feb 1975	34°17'12"N 119°42'47"W	600	Sand Silt Clay	20 64 16	2 x 4 (clay)	3.20		no fire					1. System did not fire, a new, reusable arming device was used, and it malfunctioned, a slight leak occurred by a shear disk, and the disk did not properly rupture.
XI	33	Coronado	19 Mar 1975	32°39'N 117°10'30"W	48	Sand overlying rock		1-1/2 x 3 (sand)	3.50	– 29.40	not measured		366	not measured		1. Anchor used in an amphibious operation, not intended for recovery. 2. Sediment fluke fired into rock overlain by shallow sediment, and the fluke was damaged, sediment thickness was not sufficient for fluke keying. The linkage did not break, and the fluke was recovered. The installation barge was erroneously placed over a rock ledge.
	34	Coronado	19 Mar 1975	32°39'N 117°10'30"W	49	Sand overlying rock		1-1/2 x 3 (sand)	3.50		no fire					1. System did not fire, the new, reusable arming device malfunctioned. A procedure, which did not properly check firing pin clearance in its firing chamber, was used to improve the safety margin for firing in shallow water. This procedure has been modified, and additional bench testing of this reusable system has been performed.
	35-36	Coronado	20 Mar 1975	32°39'N 117°10'30"W	55, 52	Sand		1-1/2 x 3 (sand)	3.50	– 29.40	not measured		366	not measured		1. Anchors used in an amphibious operation. Flukes were proof-tested by pulling with the warping tug. After the operation an attempt to free the anchors was made by rapidly jerking the anchor line, neither anchor could be pulled free, and the lines were cut. 2. A larger 7/8-in. wire was used in place of the 3/4-in. wire to fully develop the sand fluke capabilities.

*Estimated from Key Dis = 1-3/4 x fluke length.

Only one test (test 31) was performed in a predominately silt seafloor. Site information to 10 feet indicated a reasonably competent material would be encountered at the expected penetration depth of 20 to 30 feet; as a result, the small sand fluke was chosen. This trend proved to be false; soil shear strength did not increase with depth at the rate expected as evidenced by the soil recovered from the fluke. The holding capacity was 28,000 pounds, more than design, but less than what should have been obtained from the larger 2 x 4-foot clay fluke, which is more optimum for this intermediate strength soil.

Tests results in stiff clay also indicate that the nominal design capacity is readily achieved; in particular, note test 23. This stiff clay was found in 12,200 feet about 120 miles off Norfolk, Virginia. The exact composition of the seafloor was unknown when the small sand/stiff clay fluke was chosen; it was a lucky choice. Seafloor composition was determined from the soil recovered on the fluke and from a subsequent unsuccessful attempt (later coring cruise) to take a long core. The corer bent after penetrating a few feet of surficial silt.

Several tests were performed in soft clay, and the results are inconclusive. This is due to the variation in holding capacity for soft clay even though various fluke sizes are used. The short-term holding capacities of both small and large flukes were generally about 20,000 pounds, except for tests 21 and 22 where an extremely soft hemipelagic clay was encountered. The small fluke was used for test 21, which resulted in 13 kips, and the 2 x 4-foot fluke was used for test 22. The 8-kip load recorded for test 22 is misleading because the fluke penetrated deeper than expected, thereby apparently damaging the cable and fittings when it ran out of cable travel while moving. As the downhaul cable was being brought on deck, it was noticed that it had a badly damaged fitting and that the fluke was not hanging on the line. This fitting parted under only the cable's weight and fell to the seafloor. A longer downhaul cable was used in all subsequent tests in soft clay. The larger clay fluke could have been used for each of these tests.

Test 27 was performed in a red clay, north of Hawaii. It was difficult to keep the main load line in line with the axis of the dynamometer sheave; therefore, false readings were recorded during the test. Actual values were determined through post calibration. The 17-to-24-kip range indicates the degree of uncertainty evident during post-calibration.

Rock Tests

Only three tests were completed in rock and a rock conglomerate — tests 11, 12, and 29. The results, which were scattered, indicate that considerably more testing in this general type of seafloor is necessary to more clearly define behavior. One test, test 11, resulted in a spectacular holding capacity of 107,000 pounds in direct uplift with only 2-1/2 feet of penetration in basalt. Test 12 in the same area resulted in a capacity of 20,000 pounds with a total penetration of 7 feet. A 20-to-30-foot-diameter plateau with 45-to-60-degree sloping sides was used for both tests. The first fluke was fired directly into the center of the plateau, while the second hit the slope; it was surprising that the second one even penetrated. The basalt on the slope was very weathered and fractured easily. The basalt in the center did not fracture; the fluke just became wedged in the basalt. In the same general vicinity of Anacapa Island, a third test was performed (test 29) in a rock conglomerate. Solid basalt was desired; the conglomerate was unexpected. Nonetheless, the holding capacity was 30,000 pounds in what divers described as a rubble. Keying in this material would have been desirable.

DISCUSSION

Test Correlation

An attempt was made to find an empirical parameter that would suitably describe observed short-term anchor performance. This effort resulted in Figure 18, which is a plot of the parameter η, the ratio between measured holding capacity and kinetic energy, versus general soil type. Three distinct phases were apparent when looking at the parameter η, and they were best separated by soil type. The reasons for this reasonably good correlation are not yet apparent. In fact it is somewhat contradictory to expected behavior. For example, the plot indicates that holding capacity is controlled more by the available kinetic energy than fluke size, especially for the soft clay where the majority of data exists. It indicates that with equal kinetic energy, a small fluke will hold

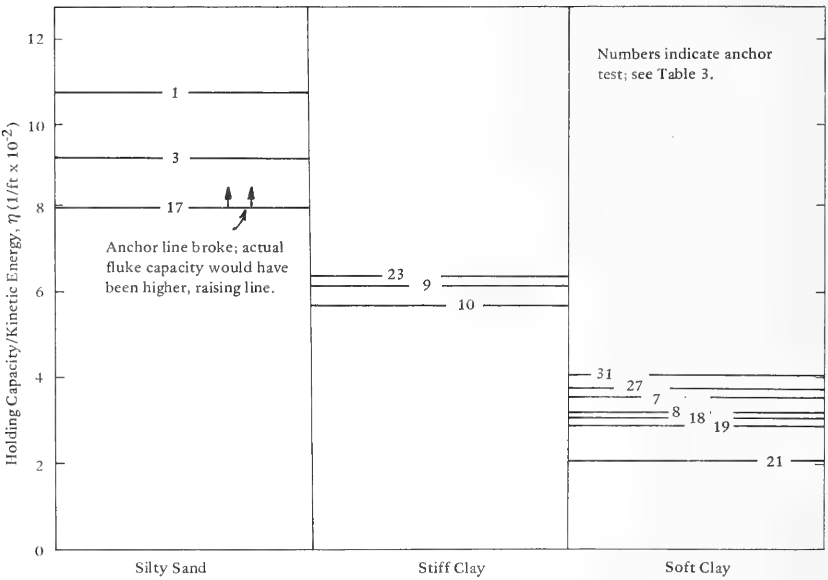


Figure 18. Relationship between the parameter η (holding capacity/kinetic energy) and soil type.

(short-term) as much as a large fluke. One possible explanation for this is that the large flukes create much more soil disturbance during dynamic penetration than do the small flukes. A method of countering this phenomenon would be to wait a day or week, depending upon the rate of strength regain through thixotropy or reconsolidation, to fully load the anchor flukes. Also, in a highly sensitive seafloor material the long-term capacity would far exceed the measured short-term capacity. Another distinct possibility is that the large flukes are not keying or take considerably longer to key than expected in soft sensitive clay. Both possibilities, disturbance and poor keying behavior in soft clays, are being explored through small-scale field tests and laboratory model tests.

The parameter η can be used to get a better idea of what force would have been required to pull out the fluke in test 17 if the line had not parted. Assuming a medium value of 10×10^{-2} for η instead of the recorded 8×10^{-2}, the short-term holding capacity would have been 72 kips, which is 25% greater than the peak recorded load of 58 kips. If this plot could be verified with more data, then it would provide a quick method of determining a specific range of short-term holding capacity with only limited site information. It is probable that the parameter η can be related to a specific seafloor property, possibly undrained shear strength, to more clearly express the short-term behavior of propellant-actuated embedment anchors. This possibility and others are being fully explored at CEL; the results of the theoretical and empirical investigations will be reported at a later date.

Performance of Device

The 20K anchor has operated successfully in clays, silts, sand, rock, and rock conglomerate.

Holding capacities equal to or exceeding the 20,000-pound design capacity have been achieved in these seafloors. The most consistent performance has been in sands and silty sand. Operability in water depths of 50 to 20,000 feet has been demonstrated by ocean and ocean-simulation testing. Actual firing has occurred in water from 48 to 18,700 feet, and the device has been subjected to 20,000 feet of water pressure in a pressure chamber. This is a satisfactory demonstration that the system will operate at 20,000 feet in as much as the gun chamber is sealed and the electronics and cartridge assembly operate at atmospheric pressure.

Several attempts were made to reduce the cost of the anchor by eliminating the fluke linkage and attaching the downhaul cable directly to the fluke at its eccentric connection point. This did not work very well because the piston would not separate as the fluke was pulled vertically, thus preventing or delaying keying. This technique could probably be used in coral, but the linkage should be used in sediment unless a more positive fluke/piston separation scheme can be designed. The anchor, which can be quickly assembled, is easily handled and deployed from a variety of vessels with limited to well-developed handling capabilities, such as a Navy warping tug, cable layer (ARC), ARS, and ATF.

The structural integrity of the system has been verified through multiple firings with the same gun assembly and flukes. There have been no sealing difficulties with the anchor; this is attributed to the checkout procedure which involves applying a vacuum to each pressure-resistant chamber prior to deployment.The anchor has been tested or utilized 36 times with 10 nonfires. These were primarily caused by malfunctions in either the touchdown assembly or the safe-and-arm device. The touchdown assembly was redesigned after test number 5, and it has since operated with high reliability except for test 20 where the magnetic switch malfunctioned. In this type of malfunction the anchor simply does not fire and is brought on deck in a safe condition. The magnetic switch is normally a high reliability item that is pressure-checked before use.

The safe-and-arm device was redesigned after test 16 where four nonfires occurred in rapid succession, all caused by leaking inflators below the gas bottle. The aluminum inflators were eliminated and subsequent to this change, there were no further problems with the ordnance S/A.

A nonordnance S/A was introduced into the system at test 30. The nonfires of tests 32 and 34 were caused by malfunctions in this unit. This new S/A has since received considerable bench testing and has been used in 27 additional anchor firings as part of other programs with excellent reliability. In only one instance did the S/A fail to fire the charge, and this was caused by an empty gas canister. This could have been caused by human error or a faulty one-way valve on the canister. In any event, the system was safe when brought on deck, and the S/A was replaced. The new, reusable S/A reduces the cost of each shallow-water anchor firing (<600 feet) by 40%.

This anchor was designed and fabricated to prove that the idea of using a propellant-actuated anchor in a large range of water depths, particularly very deep water, and in the range of anticipated deep-ocean seafloors was a practical alternative to conventional anchors. Based upon the test results, the idea is practicable. It now remains to maximize anchor flexibility by varying the configuration as necessary to reduce cost and to devise installation techniques to simplify and speed anchor deployment. The existing technique for deep-water installation utilizes a single lowering anchor line, which results in the loss of the gun assembly (Figure 19). Even considering this loss, however, total anchoring cost is still less than that for conventional anchors.

Appendix B describes some alternate procedures for installing the anchor system and some techniques for reducing anchoring cost by retrieving some of the components. It is probable that the most efficient installation/recovery technique for any particular set of conditions is not described. However, the best technique could possibly be devised through a combination of the methods. The maximum estimated water depth for each technique is listed for each method.

SUMMARY

The CEL 20K anchor has satisfied the operational criteria defined at the inception of development by:

(a) operating successfully in a wide range of seafloor types (from soft clay to hard rock)

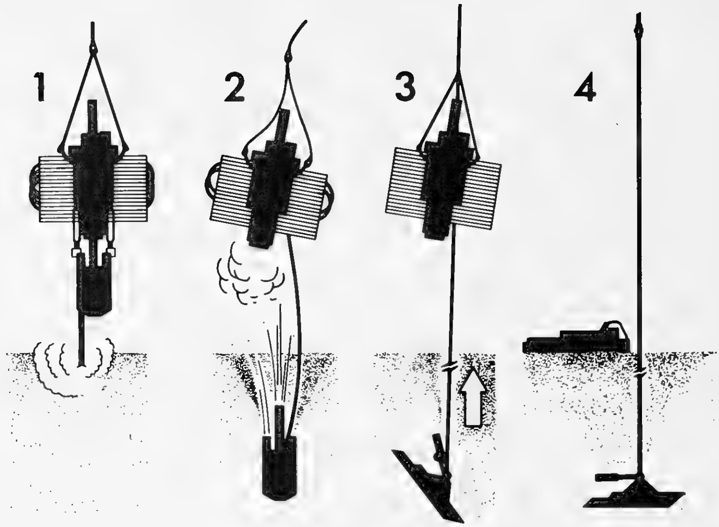


Figure 19. Single-line installation technique for the deep-water anchor (with sediment fluke).

(b) equaling or exceeding its design holding capacity of 20,000 pounds in these seafloors

(c) demonstrating that it is functional in water depths from 50 to 20,000 feet

The anchor is quickly assembled and can be easily handled and deployed from a variety of vessels, including ATF, ARS, ARC, Buoy tender, and Navy warping tug. Anchor cost for shallow-water operations ($<$600 feet) has been reduced by up to 40% through a new, reusable safe-and-arm device for the system. The cost of the nonrecoverable items per anchor firing in shallow water is now $1,400. In deep water, assuming that the launching system is not recovered, the total cost is $4,500 per anchor firing ($3,100 of which is the launching system).

The idea that propellant-actuated anchors offer practical alternatives to conventional anchors has been supported by the available tests and operational uses of the anchor. High efficiency, light weight, ease of handling, adaptability, multidirectional load-resisting capability, and low cost are a few of the anchor's qualities that support this contention.

Practical methods for installing the 20K anchor, for recovering the anchor, and for recovering anchor components in deep water have been conceived. Use of this anchor will expand once these procedures, which eliminate total dependence upon single-line lowering and deep-water launching system expendability, are tried and perfected.

The testing accomplished so far has been limited and designed principally to determine whether the anchor works. There has not been enough testing to

properly define anchor reliability and performance in the wide range of conditions that could be encountered in the deep ocean. Therefore, additional testing of the anchor and work to improve anchor reliability and flexibility of operation are justified.

ACKNOWLEDGMENTS

Al Horst of the Gun Systems Engineering Branch, Naval Ordnance Station, designed and tested the ordnance system for the 20K anchor. Dave Ramsted and Tom Waugh, Naval Underwater Systems Center, designed the safe-and-arming devices. Particular appreciation is extended to Phillip Babineau, CEL Engineering Technician, who assisted in all phases of test and evaluation and whose many innovations have made the anchor simpler and safer to operate and handle.

REFERENCES

1. Civil Engineering Laboratory. Handbook of uplift resisting anchors, by R. J. Taylor, D. Jones, and R. M. Beard. Port Hueneme, CA, Sep 1975.

2. ——. SEACON II operations plan, by T. Kretschmer et al. Port Hueneme, CA, Jul 1974.

3. Naval Civil Engineering Laboratory. Technical Note N-1186: Explosive anchor for salvage operations – Progress and status, by J. E. Smith. Port Hueneme, CA, Oct 1971.

4. Naval Ships Systems Command. U. S. Navy Ship Salvage Manual, vol 1: Theory of strandings and the use of beach gear. Washington, DC, Nov 1968.

5. Hydrospace Research Corporation. Report 111: Technical summary of five deep sea ship moors. 1964.

6. Naval Civil Engineering Laboratory. Technical Note N-1282: Propellant-actuated deep water anchor; interim report, by R. J. Taylor and R. M. Beard. Port Hueneme, CA, Aug 1973.

7. Civil Engineering Laboratory. Operation manual; propellant-actuated deep water anchor, by R. J. Taylor and P. Babineau. Port Hueneme, CA, Sep 1974.

8. Naval Civil Engineering Laboratory. Technical Note N-1099: Taut guideline for ocean load handling system, by C. L. Liu. Port Hueneme, CA, Jun 1970.

9. U. S. Army Mobility Equipment Research and Development Center. Report 2016: Air-transportable mooring construction system for T-5 tankers, by H. C. Mayo. Fort Belvoir, VA, Nov 71.

10. S. N. Marep Company Literature. 28BD De Grenelle, Paris, Jul 1969.

11. Civil Engineering Laboratory. Technical Report R- : Expedient mooring system, by D. G. True. Port Hueneme, CA (in preparation)

Appendix A

DETAILED TEST SUMMARY FOR THE CEL 20K ANCHOR

TEST OPERATION I

These tests constitute the first in water firings of the 20K anchor. The principal concern was fluke performance because land testing of the fluke was impractical. Two tests were planned using reduced, but progressively increasing, charge weights. The CEL shallow-water (110 feet) test site was used. Tests were performed from the CEL warping tug.

Test 1 (6 Dec 72)

Very little difficulty was encountered in handling and quickly lowering the anchor to the seafloor. The anchor fired upon bottom contact and embedded the fluke 12-1/2 feet before keying. Penetration was recorded by diver placement of a marker on the down-haul cable at the point it entered the seafloor. With a springline attached to the anchor, load was increased in about 10-kip increments until failure occurred in about 5 minutes at a load slightly in excess of 42,000 pounds. Peak gun pressures recorded from copper crush gages placed in the cartridge were 16,500 psi and 16,000 psi. Inspection of the anchor upon return to the surface revealed practically no damage. The electronics in the power package were undamaged, the batteries could be recharged, the fluke and piston were totally reusable, and the non-ordnance portion of the S/A was reusable. Considerable difficulty was experienced in removing the S/A from the breechblock after firing. This would be significant in shallow water use where the anchor system is recoverable.

Test 2 (6 Dec 72)

The anchor did not fire upon bottom contact. After 30 minutes, the anchor was brought to the surface and inspected. Since the S/A had not been activated, the anchor was safe and could, therefore, be brought on deck. The only problem that could be detected was that the hydrostatic switch closed at 49 psi, which is greater than that required for firing at 100 feet. The switch was tested several additional times, and it closed at 30 psi each time. The switch was replaced, and the anchor readied for another test.

Test 3 (7 Dec 72)

The anchor fired successfully upon contact with the seafloor, embedding the fluke about 15 feet into the dense silt bottom. Load was slowly applied, and the anchor pulled out at 48,000 pounds in about 5 minutes. The average measured gun pressure was 22,300 psi; predicted pressure was 24,522 psi. This difference was attributed to the temperature of the propellant. Properties used in the prediction scheme are determined from cartridges prewarmed to 88°F. The test cartridges were stored in a cold location; performance can be affected by up to 100 psi per degree F. Inspection of the anchor revealed no damage during firing or at pullout.

TEST OPERATION II

The purpose of these anchor tests was to take the anchor into progressively deeper waters while performing tests in soils with well-known properties. This series of tests was performed from the MV *Gear* (ARS).

Tests 4 and 5 (6 Feb 73)

Both tests resulted in misfires. The cause was attributed to the touchdown firing assembly. Apparently the magnetic field was being degraded in deep water. The system functioned reliably on deck, and, as a result, this problem could only be surmised. To rectify this assumed problem, the magnetic switch assembly was isolated from the steel fluke, and the orientation of the magnet with respect to the switch was changed to increase the strength of the magnetic field. This redesign apparently worked, because the system has functioned reliably in all subsequent tests.

Test 6 (7 Feb 73)

This test was also performed at the SEACON I site in 550 feet of water. The fluke used did not have linkage; the down-haul cable went directly to the eccentric connection point. This technique, if it worked, would reduce the fluke/piston cost by about 50%. Load was applied to the anchor by taking successive purchases with the salvage vessel's beach gear leg. The fluke pulled out with practically no load. The piston did not eject from its receptacle, thereby preventing keying of the fluke. This connection technique still appeared promising provided the height of the piston receptacle could be reduced to allow the piston to freely dislodge during keying. Predicted gun barrel pressure was 14,500 psi; actual was 16,600 psi.

Test 7 (7 Feb 1973)

This test was performed in 900 feet of water. The 1-1/2 x 3-foot sand fluke with linkage was used with a 3.25-pound charge. The anchor fired on bottom contact, embedding 20 feet. Gun barrel pressure was not recorded; the copper crush gages placed in the cartridge were lost during firing. The maximum load recorded during pullout was 20,000 pounds. The anchor pulled out while resetting the beach gear leg. The actual pullout load could have been somewhat larger than the recorded load. In future tests, the anchor should be pulled by ship's power to provide more control. Total penetration of the fluke was 42 feet after keying.

Test 8 (7 Feb 73)

This test was performed at the CEL 1,200-foot site using the 2-1/2 x 5-foot clay fluke with a 2.75-pound charge; the anchor fired properly. Loading procedure first involved removing the slack from the main line by taking up with the wing drum slowly. By mistake, line was taken in until the wing drum stalled, and the line was stoppered off. Stalling load on the winch was 30,000 pounds; ship motion could exaggerate this load considerably. Next, the load cell was attached, and the ship was backed down to pull the anchor out. Actual measured load was 17,000 pounds, but the load could have been anywhere from 17,000 to 40,000 pounds. There was about a 10-kip surge effect. There was very little success in controlling the loading of the anchors from the ARS. Total penetration of the fluke after keying was 32 feet.

Test 9 (8 Feb 73)

Prior to the installation of SEACON II* in which the 20K anchor would be used, it was decided to perform a couple of tests to determine the most suitable fluke sizes. This was necessary because a long core could not be obtained at this site. The 1-1/2 x 3-foot sand fluke was used with a 3.25-pound charge. Load was applied differently during this test. The ship was allowed to drift until the line became taut; then the ship's speed was increased slowly. This proved to be an excellent method for controlling the load. The load was increased to 36,000 pounds, at which time the skipper decided to back the ship down to avoid fouling the screws with the line. (It was doubtful that this would occur.) The ship was moved more rapidly in reverse than desired, causing the line to suddenly become taut at which time the anchor pulled out at 30,000 pounds. Total penetration of the fluke after keying was 18 feet.

Test 10 (8 Feb 73)

The second firing at SEACON II utilized a 2 x 4-foot clay fluke with a 2.75-pound charge. Load was applied by slowly backing down the ship. The anchor pulled out at 27,200 pounds. Load was applied quite rapidly with pullout occurring in less than 1 minute, even though care was exercised in controlling the ship's speed. To date it has been extremely difficult to perform controlled deep-ocean test loadings. Total penetration of the anchor fluke after keying was 23 feet. The seafloor was less sandy than that at test 9, which was about a mile away. Even though the seafloor was apparently somewhat variable at this site, the decision to use the sand fluke for SEACON II was made.

TEST OPERATION III

Two tests with the 20K anchor were performed in a basalt seafloor just north of Anacapa Island (20

* An instrumented cabled structure in 3,000 feet of water.

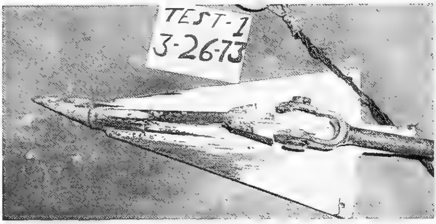
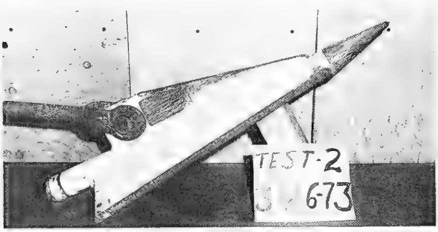


Figure A-1. Rock anchor after first test (Test 11) in basalt.

(a) Back view.



(b) Side view.

Figure A-2. Rock anchor after second test (Test 12) in basalt.

miles from Port Hueneme) in 67 feet of water. The CEL warping tug was used as the test platform.

Test 11 (26 Mar 73)

A 3.75-pound charge was used with the 1-1/2 x 3-foot rock projectile. The anchor fired and embedded 30 inches to the point of cable attachment. The warping tug was backed off about 50 feet, and load was increased to 100,000 pounds and held for about 10 minutes. The tug was moved directly over the anchor, and 107,000 pounds were required for pullout. Figure A-1 shows the rock fluke after pullout. The fluke nose was bent at its threaded attachment point to the main shaft. Also, the piston receptacle was elongated, which indicates that the fluke tried to move laterally from its fired line of direction. No other damage occurred to the fluke.

Test 12 (26 Mar 73)

The anchor was again fired using a 3.75-pound charge. The seas had picked up considerably, and it was becoming difficult to maintain position above the 30-foot-diameter basalt plateau that was being used for the tests. When the tug's position was considered to be correct, the anchor was rapidly lowered until touchdown. The plateau was missed, and the anchor fired and embedded into the 45-to-60-degree slope leading to the base of the plateau. Penetration was somewhat in excess of 7 feet; 4 feet of rock slope was shattered before the fluke embedded to the cable connection. Figure A-2 shows the fluke after pullout. The markings on the painted surface and the upturned nose indicate that this fluke also travelled laterally during penetration. The basalt on this slope was obviously weathered, and this resulted in a reduced holding capacity of 20,000 pounds.

Future rock flukes will be fabricated without the 4340 hardened steel nose which is threaded on the central 4140 steel shaft. The 4140 shaft will be machined with a tapered nose to significantly reduce cost.

TEST OPERATION IV

This operation was conducted to determine anchor performance in a coral seafloor and then in very deep water (10,000 feet). All tests were performed off Hawaii from the USCG Cutter *Buttomwood.*

Tests 13-15 (26-28 Jun 73)

These three attempts resulted in misfires. All were attributed to malfunctions in the safe-and-arm device. There were no leaks in the anchor system, and the touchdown firing mechanism was functioning as intended. In each misfire the gold shear disk (refer to the equipment description in the main text) was bowed to incipient failure. Either the shear disks were rated at a higher pressure than 400 psi or the gas cartridge was leaking, causing pressure reduction to a point less than the required 400 psi. Another possibility was that one of the solenoid valves was operating improperly. All new components were subsequently brought to Hawaii by the S/A designer, and a series of bench tests was performed; on board the ship the S/A functioned correctly each time. Since the primary reason for this operation was a deep-water trial, one attempt would be made at 10,000 feet.

Test 16 (29 Jun 73)

The seas were rough (sea state 4^+); however, the captain was sure that the anchor could be handled safely. The anchor was lowered by cathead with a backup set of bitts to 10,000 feet in 75 minutes. Firing was not detected by a hydrophone placed at about 100 feet; however, the ship was allowed to drift until load was applied in case firing had occurred. After an hour the anchor was retrieved when it became certain that the ship was not anchored. Anchor retrieval took 3-1/2 hours; it was long, but not tedious. The anchor had not fired, but it was in a safe condition. Again the unit was completely dry internally, and the misfire was caused by an S/A malfunction. The gold shear disk was bowed but did not fail.

Upon return to CEL, the S/As were thoroughly checked, with the problem being detected. The aluminum inflators were not pressure-tight; the gas was leaking through the casting seams. This was not detected earlier because the leaks were very slow, and all previous tests had been generally accomplished quickly. But each test in Hawaii took a considerable period of time. In the shallow-water coral tests the anchor remained suspended above the seafloor for long periods, because it was difficult to locate reasonably clear, coral sites. In deep water, the S/A was enabled for almost 2 hours before touchdown.

This problem was quickly solved by first eliminating the aluminum inflators and replacing them with stainless steel seamless inflators. The entire valving assembly is immersed in a dielectric fluid to detect leakage prior to assembling the S/A. Eventually the inflator and gas cartridge were replaced by a gas canister with a one-way valve. There have been no problems with this assembly since these improvements.

TEST OPERATION V

The purpose of these tests were twofold; first, to verify performance of the S/A subsequent to the modifications, and second, to generate test data in soft clay. All tests were performed from the CEL warping tug.

Test 17 (4 Dec 73)

This test was performed at the CEL shallow-water test site in 150 feet of water. Firing occurred, with the fluke penetrating about 20 feet to the fluke tip. Load was increased slowly until the anchor downhaul cable parted at 58,000 pounds.* The actual capacity was, therefore, undetermined in this silty sand seafloor.

Test 18 (5 Dec 73)

At the CEL 1,200-foot site, a 2 x 4-foot sediment fluke was embedded, using a 3.25-pound charge, into soft clay to a depth of 34 feet. Load was applied in a slow, continuous manner until pullout at 20,000 pounds; this load was lower than expected. It is possible that the fluke causes significantly more disturbance to the soil during dynamic penetration. This

* 58,000 pounds is exactly the line breaking strength.

phenomenon will be investigated during small anchor projectile tests in San Francisco Bay mud. Also, perhaps it is simpler to pull the anchor vertically through the soil remolded during penetration than it is to penetrate the stiffer walls of the remolded cavity. In future test operations, the clay anchor flukes will be improved to maximize performance in soft clay by sharpening the top edge of the fluke to aid keying and by sand-painting the fluke surface to increase soil adhesion.

Test 19 (5 Dec 73)

At the 1,200-foot site, the 2.5 x 5-foot clay fluke, which was fired with a 3.0-pound charge, penetrated the soft clay to a depth of 40 feet. The fluke did not have linkage. This was similar to the technique of Test 6; however, the piston receptacle was enlarged. Load was gradually increased until pullout at 19,000 pounds. When the anchor was recovered, there was no sediment in the piston receptacle, which indicates the piston did not separate and, therefore, the fluke did not key.

TEST OPERATION VI

These tests were performed about 150 miles off Norfolk, Virginia, from the cable layer USNS *Aeolus*. An attempt was made to gather seafloor engineering data at the proposed test sites from another vessel; mechanical problems on that ship caused a delay until after the anchor tests. A more suitable choice of flukes could have been made with this data.

Test 20 (20 Jul 74)

The anchor was assembled with the 1-1/2 x 3-foot sand fluke, because the seafloor characteristics were unknown. Water depth was 8,000 feet. There was insufficient clearance to take the anchor over the bow sheaves vertically; therefore, it was laid horizontally and passed beneath the gantry until it cleared the sheaves. Then it was placed in an upright position and lowered at 300 ft/min to the seafloor. The anchor did not fire, and it was brought back on deck for an autopsy. A dead spot was found in the magnetic switch assembly. The magnetic switch could get by the magnet without closing the switch. The next day was spent improving the switch assembly to ensure that the magnet passed within 1/4 inch of the magnetic switch. This problem has not since reoccurred.

Test 21 (22 Jul 74)

The 1-1/2 x 3-foot fluke was used with a 3.2-pound charge. This charge weight was somewhat less than optimum. Originally, tests were to be run at 6,000 and 12,000 feet; however, circumstances while at sea caused a change to 8,000 and 12,000. As a result, a previously loaded charge optimized for a depth other than 8,000 feet had to be used. The anchor was transferred horizontally over the bow sheaves and set upright for lowering. Firing occurred on bottom contact; load was then applied until pull-out at a net load at the anchor of 12,000 to 14,000 pounds. This indicates a very soft seafloor and that a larger fluke would have been more suitable.

Test 22 (23 Jul 74)

A 2 x 4-foot fluke was used with a 3.1-pound charge. The anchor fired and was loaded until pullout occurred at a net anchor load of about 8,000 pounds. The gun assembly and the fluke down-haul cable attach directly to a ground ring above the gun assembly. The gun assembly was brought on deck, but before the down-haul cable could be secured, it separated. The open socket on the cable had opened and allowed the cable to fall to the seafloor. The fluke was not attached to the lower end of the cable. Apparently, the 100-foot down-haul cable was not sufficiently long to accommodate fluke penetration and launch vehicle recoil in this very soft soil. As a result, the fluke damaged the fitting to the ground ring when it reached the end of line travel. Future test installations in these soft seafloors will require a longer down-haul cable.

Test 23 (23 Jul 74)

At 12,200 feet, the 1-1/2 x 3-foot was used with a 3.2-pound charge; the anchor fired upon bottom contact. This test involved first setting the anchor by vertical pull and then loading the anchor laterally after paying out additional line. Ship's power was

used to apply load until pullout occurred at a net load at the anchor of 40,000 pounds. Soil taken from the fluke was stiff, hemipelagic clay.

TEST OPERATION VII

Three anchors were installed as part of the CEL SEACON II experiment. One anchor was to be part of a construction moor and two were to moor two legs of a tri-legged instrumented cabled structure. This operation constituted the first time the 20K anchor would be used in an actual installation. The sand fluke was chosen for each installation, as per results of Tests 9 and 10.

Test 24 (5 Aug 74)

A 3.6-pound charge was considered optimum for this water depth. Once the anchor fired, a test pull of about 25,000 pounds was applied for 10 minutes; the anchor did not pull out.

This anchor has been in service for over a year. An 8-foot-diameter mooring buoy with a net buoyancy of 15,000 pounds is attached via 4,000 feet of wire rope to the anchor in 2,630 feet of water. The 140-foot CEL warping tug has moored to this buoy and used it for reaction while pulling the cabled structure under water. Also, a 75-foot fishing vessel was moored to the buoy for 16 hours during sea state 6 sea conditions. Loads were sufficiently great to periodically submerge the mooring buoy.

Tests 25 and 26 (5 Aug 75)

Both anchors were installed with 3.25-pound charges. The reduced charges were chosen because the actual in-service loads would not exceed a few thousand pounds. Each anchor was embedded 25 feet after setting the anchor flukes. These depths were accurately measured with a transponder placed 50 feet above the gun assembly. Test pulls of 15,000 pounds were applied to each anchor for 10 minutes.

TEST OPERATION VIII

The purpose of this test (Test 27, 23 Sep 74) was to verify the performance of the 20K anchor at close to its maximum design water depth. The USS *Conserver* (ARS) was used as the test platform.

Twenty-four thousand feet of 2-inch synthetic line was used as the main lowering line. Since part of this line was borrowed, a weak link was placed in the down-haul cable to protect the synthetic line. Geological data indicated that the seafloor was a soft red clay. To make the test more meaningful, the 1-1/2 x 3-foot fluke was chosen with a 2.75-pound charge to ensure pullout at a load less than the weak link strength of 27,500 pounds. Lowering to 18,700 feet took about 1-1/2 hours. Firing was not detected with the ship's hydrophone. This was not at all surprising since there was considerable noise interference. Line was retrieved slowly, and it appeared that the anchor had embedded. The dynamometer was not recording the load accurately, but the traction unit behaved as if the load were quite high. It was difficult to keep the line centrally located over the dynamometer shieve; as a result, the loads were incorrect. A post calibration of the dynamometer with the line angled in the same direction showed that the peak pullout load was between 17,000 to 24,000 pounds.

TEST OPERATION IX

The purpose of these tests was to supplement the limited test data for anchor performance in a rock seafloor. Tests were performed off Anacapa Island (about 20 miles from Port Hueneme) from the CEL warping tug in 60 feet of water.

Test 28 (6 Dec 74)

Divers located a flat, rock seafloor in 60 feet of water. The rock projectile was used with a 3.75-pound charge. Firing occurred, and divers were sent to photograph the anchor. Penetration was deep, not into competent basalt, but into a cemented rock conglomerate overlying sand. The open socket attached to the fluke was fractured; the piston apparently ejected prematurely and impacted the socket. This had not occurred in two previous tests in rock (Tests 11 and 12), because solid rock was encountered, and lateral projectile movement was minimized. Flukes fabricated subsequent to this operation will be modified by welding the main plates at 180 degrees vice 140 degrees.

Test 29 (6 Dec 74)

The warping tug was moved about 100 yards, because the divers indicated that the seafloor appeared to be more competent but uneven with considerably more boulders. The anchor fired and embedded. Load was applied in direct uplift until pullout occurred at 30,000 pounds. The fluke and piston were recovered; the piston receptacle was elongated, indicating that the piston and fluke had tried to separate during penetration. This action should be eliminated with the modifications designated in Test 28. This test was significant in two respects; first, the anchor fired and embedded successfully in a very uneven rocky seafloor, and second, the anchor held more then expected in direct uplift in this very difficult seafloor.

TEST OPERATION X

The purpose of this cruise was to gather more test data in silt and soft clay. Only minimal data had been gathered in these materials in the past. Testing was performed from the CEL warping tug at the CEL 600- and 1,200-foot sites in the Santa Barbara Channel.

Test 30 (25 Feb 75)

Available soils data (limited to 10 feet) at the 600-foot site indicated that the 1-1/2 x 3-foot fluke would be optimum. A peak charge of 3.6 pounds was used. The anchor fired and embedded; however, a link to the fluke fractured during penetration. The fluke possibly hit something on the seafloor, or the link could have been defective; this had not occurred previously.

Test 31 (25 Feb 75)

A second anchor, which was also prepared with the 1-1/2 x 3-foot fluke and 3.6-pound charge, was lowered to the seafloor. The anchor fired and embedded 24 to 26 feet. Load was applied slowly until pullout occurred at 28,000 pounds. The soil recovered from the fluke was a nonplastic silt, which was much less stiff than anticipated from the 10 feet of available core data. A greater holding capacity would have been achieved with the 2 x 4-foot clay fluke.

Test 32 (26 Feb 75)

To verify that the 2 x 4-foot fluke was optimum for the seafloor conditions at the 600-foot site, one additional test was scheduled. The anchor misfired and was disarmed by Navy EOD divers. The misfire was attributed to a malfunction in the new, reusable safe-and-arm device. This was the sixth use of the new device, and it had functioned satisfactorily to date. The shear disk had not failed, because one solenoid valve malfunctioned, preventing pressure release from the gas bottle. The firing pin was still, however, pushed down. This caused the in-line/out-of-line plunger to be in line – the unsafe position. The anchor should have been safe upon return to the surface, but pressure had leaked by the gold shear disk. Two things will be done to the reusable S/A to further improve its safety characteristics. An O-ring will be placed in the chamber at the shear disk base to guarantee a seal. When properly assembled, the shear disk alone is supposed to prevent pressure bypass; the O-ring will provide a backup seal. Second, a one-way valve will be installed in the S/A housing to reduce chamber pressure, in the event of a misfire, to about 2 psi. The available pressure to fire the anchor would then be reduced 1,100 psi to 2 psi.

TEST OPERATION XI

The purpose of these installations was to install four 20K anchors in a sand seafloor about 1 mile offshore from Coronado, California, to moor a lash barge for helicopter off-loading. All installations were completed from a Navy warping tug. Modifications to the 20K anchor had to be made, because the installations were in less than 60 to 70 feet of water, the practical upper anchor firing limit. The reaction vessel was changed by adding a 36-inch-diameter plate to reduce recoil from 30 feet to about 15 feet. Also, by using the S/A in-line/out-of-line plunger, which was designed to arm at 50 feet, with a U-cup seal to replace the standard O-ring, a consistent arming depth of 27 feet could be achieved. With a 10-foot safety margin, firing in 47 feet of water was possible. The 1-1/2 x 3-foot fluke was chosen with a 3.5-pound charge for each installation.

Figure A-3. Method employed to deploy CEL 20K anchor from Navy warping tug when crane or boom is unavailable.

Test 33 (19 Mar 75)

The anchor, which was handled beneath the A-frame on the warping tug, was lowered to the seafloor. The anchor fired, the gun assembly was recovered, a buoy was attached to the line, and it was overboarded. There was no test pull on the anchor. Of interest was the method with which the anchor was handled from a vessel with no boom or crane. Figure A-3 shows the anchor just prior to being lifted off the pallet beneath the A-frame. The task was surprisingly simple and took only a couple of minutes to complete. Later in the day, after a three-piece causeway section was attached to the single-point mooring, the anchor broke free. The fluke was recovered and is shown in Figure A-4. The fluke hit a rock ledge after penetrating only a few feet of sand. The tug was mistakingly placed over a rock ledge. The fact that the rock did not cause the piston to separate from the fluke and break the linkage was particularly significant. This indicates that an anchor with reasonable capacity can be established in a minimum of about 10 feet of sand overlying rock. With less than this depth, the fluke could remain intact (as in this installation), but after keying, the anchor would be a "shallow" anchor and more susceptible to pullout.

Test 34 (19 Mar 75)

This installation resulted in a misfire, again attributed to the new, reusable S/A. The firing pin jammed part way down its passageway. The normal procedure for assembling the S/A is to put the firing pin in the chamber and slide it down its close tolerance passageway several times to ascertain that it slides freely. This was not done this time; the firing pin was inserted after the S/A was threaded into the breech to minimize back pressure on the arming plunger and to guarantee that it would be in line on bottom contact. This safety precaution caused a safety hazard and has been eliminated from the checkout procedures.

Tests 35 and 36 (20 Mar 75)

Two anchors were installed and test-pulled by using the impetus of the warping tug to set the flukes. The tug was not set up to apply a controlled pull. Each anchor moored various vessels; one anchor held three warping tugs for a brief period before being used to moor a three-piece causeway section. After the operation was completed, attempts were made to pull out the anchors by backing a warping tug down on a slack line. When the line goes taut, a sharp jerk load is applied to the anchor. Larger cables were used with the sand flukes to better match line and anchor resistance. A 7/8-inch 6 x 19 extra-improved plow steel wire rope now replaces a 3/4-inch 6 x 19 wire rope. The larger line will be used with all future anchors.

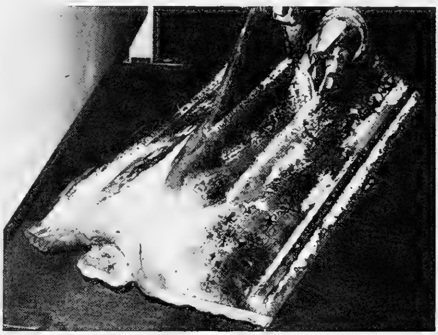


Figure A-4. Sediment fluke for CEL 20K anchor after firing into a rock seafloor.

Appendix B

ANCHOR INSTALLATION AND RECOVERY METHODS

TWO LINES (<600 feet)

This is probably the simplest shallow-water approach for retrieving the launch vehicle after each firing. As described in Figures B-1 and B-2, the technique involves one line to the gun assembly and one to the fluke assembly. The latter line must be firmly attached to the gun assembly above the figure-eight flaked portion of the line and then released upon firing. Line entanglement is prevented by maintaining considerable distance between the two lines as they are payed out. The practical limit for the technique is 600 feet, even with a 200-to-300-foot line separation. One method is to take the bitter end of the anchor line in a small boat and apply moderate lateral tension as the anchor system is lowered to the seafloor. This approach may increase depth capability. Another possibility arises from the guideline experiments of Liu in Reference 8. In these experiments, an object was lowered with just a few feet between the lines to depths of 3,000 feet without entanglement. Carefully controlled line tensions using air tuggers was the key to the successful technique. The complications of using the method to significantly increase launching system retrieval depth would have to be weighed carefully against the increased time and expense involved in recovery.

PISTON RETRIEVAL (<150 feet)

For relatively shallow water depths, the capability to retrieve the piston reduces per anchor cost by \$300 to \$400, which is a significant portion of the total cost of expendables. This retrieval method is illustrated in Figure B-3. The anchor down-haul cable (pendant) is connected directly to the keying plate; a second line is attached to a pad welded on the piston and coiled inside or on the launch vehicle. After firing, the gun assembly is retrieved, and the line to the piston, which is also connected to the gun assembly is payed out. Once on deck the piston line is placed on a capstan or winch, and the piston is pulled free of the seafloor and to the surface for eventual reuse.

BUOY-LAUNCHED ANCHOR (<600 feet)

The U.S. Army MERDC [9] uses this method with a catamaran hull for shallow-water installation of their XM50 propellant-actuated anchor when surface support is unavailable. Basically, the anchor is placed in the catamaran, which is towed to the anchor location. The anchor is lowered by winch on the buoy to the seafloor for contact firing; the catamaran buoyancy is then used to set the anchor fluke. The gun assembly is winched to the catamaran, and the catamaran is towed to shore for anchor refurbishment. In certain cases, to save time, the catamaran can also be used as the mooring buoy. Figure B-4 depicts the generalized scheme.

To extend the maximum usable depth for this method, a single lowering line, to prevent entanglement, is required. An option for either discarding or recovering the anchor gun assembly is available. Methods for recovering the gun assembly in deep water are discussed in some of the following sections.

GUN ASSEMBLY MESSENGER LINE (<3,000 feet)

The lowering line for the anchor system in this technique, Figure B-5, is also the main anchor line. Upon anchor firing, the gun assembly is released from the anchor line. Simultaneously, a small line (large enough to retrieve the gun assembly) is released and pulled from a reel or bale by a buoy to the surface. Either a rigid or inflatable buoy could be used in this method. A lightweight, low-volume high-strength Kevlar appears suitable for the retrieval line.

ANCHOR MESSENGER LINE (<3,000 feet)

This technique could be patterned after one used for the PACAN anchor [10]. In the PACAN system (Figure B-6) a braked cable drum with small diameter wire is included with the gun assembly. This wire is attached to a coupling mechanism at the bitter end of

the down-haul cable. After firing, the gun assembly is retrieved by the single lowering line as the cable reel pays out. Once the messenger line is on board, the main anchor line with couple is sent down the messenger line until coupling with the down-haul cable occurs. It is probable that water depth for this technique could be increased by using a cable bale attached to the gun assembly lowering line, at a point where there would be little restriction upon bale size.

BOOMERANG ANCHOR (<20,000 feet)

The utilization of this technique requires very little design or development. The basic idea stems from the boomerang corer. Figure B-7 illustrates the deployment and recovery of the anchor. During lowering, the system is about 100 to 200 pounds negatively buoyant. After firing the system is 100 to 400 pounds positively buoyant because of fluke assembly expulsion. Firing releases the gun assembly from the anchor line, and it returns to the surface for pickup and refurbishment. An alternate method uses an inflatable buoy, which is activated on anchor firing to recover the gun assembly. Since the system using the noninflatable buoy will only be about 100 pounds negatively buoyant, free-fall with the line strung out on the surface or flaked on deck is also a possibility.

DROGUE FREE FALL (<20,000 feet)

The depth limitation for this method, Figure B-8, is controlled solely by the design depth of the anchor seals and pressure housings. The depth can be extended as could any of the techniques described in the following paragraphs by redesigning these items. Without a drogue to retard free fall, a rapid acting arming device, a less sensitive bottom sensing mechanism, and a hydrodynamically stable shape would be required to guarantee proper firing.

The anchor can be dropped directly from a surface vessel after the anchor line has been completely laid out on the surface, or the anchor can be dropped from the primary vessel, dragging the line that is either flaked on deck or contained in a bale or on a braked reel. The boomerang method could be coupled with this to recover the gun assembly.

FLOWN-IN ANCHOR (<20,000 feet)

A technique for accurately positioning the anchor at touchdown is shown in Figure B-9. The ship moves in a line that crosses the desired implant point with the anchor being towed behind it with a synthetic line. The rate of fall and, therefore, line catenary depends upon ship speed. By monitoring anchor position and adjusting ship speed, the anchor can be precisely implanted. This procedure has been successful with conventional anchors from ships with little station-keeping ability. To prevent premature firing, the arming system would have to be modified for free-fall firing, and the anchor would have to fall vertically.

AUTO MOORING (<20,000 feet)

Many possibilities exist for rapidly and automatically installing the CEL 20K anchor; these are described in detail by True [11]. An optimum system, referred to as the expedient mooring system in True's study, was chosen that would be useful in a variety of forseeable applications. The desired goal, which was system flexibility, appears to have been achieved. The system, Figure B-10, embodies a single bale to be deployed in free-fall with the anchor. It also includes a large buoy and a line tensioning/locking device, either or both of which can be deleted from the system when not needed. The 20K anchor is attached to the cable bale housing and is encased in a hollow-nose section. The entire system is hydrodynamically stable for smooth descent to the seafloor. System flexibility allows establishment of a taut or slack subsurface or surface mooring. The system is still in the concept phase of development; however, all the components considered for this system exist. It only remains to combine them and evaluate performance.

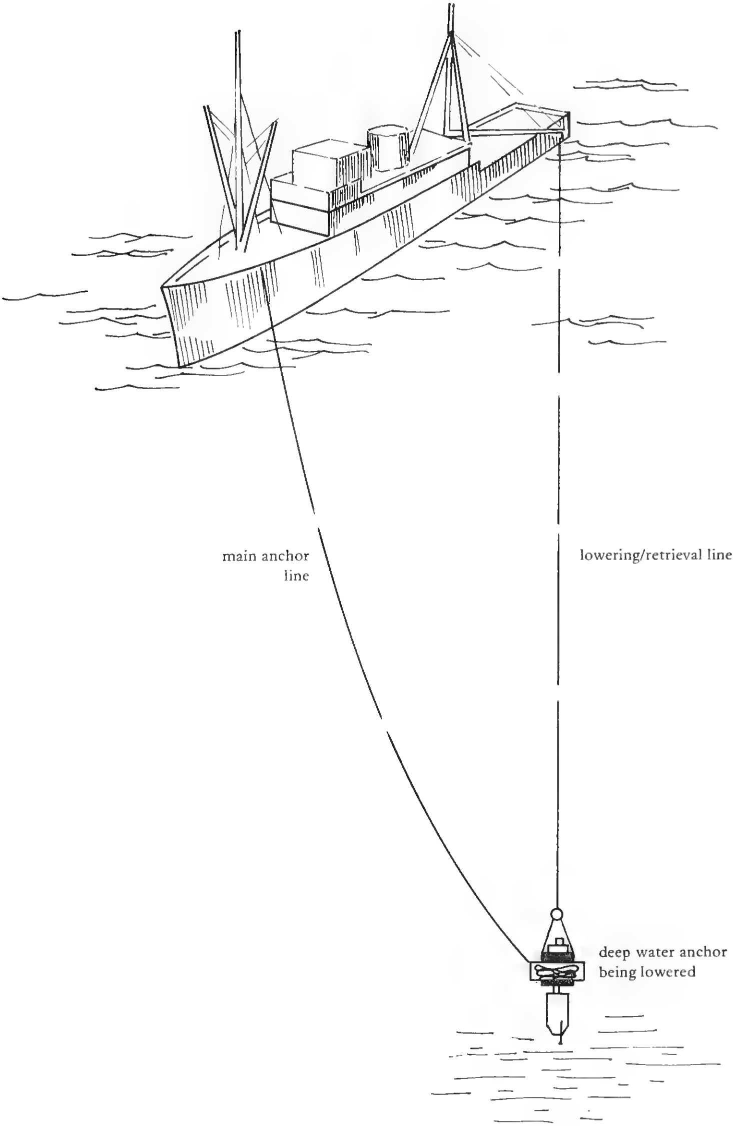


Figure B-1. Shallow-water (<600 feet), two-line anchor installation technique.

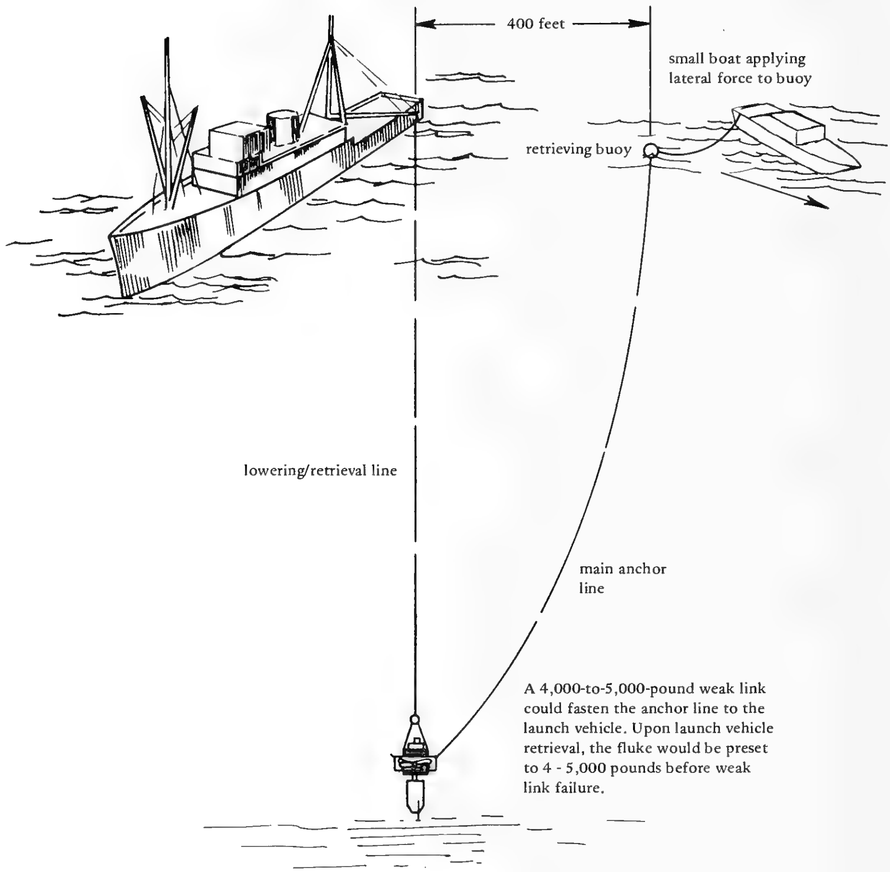


Figure B-2. Alternate shallow-water, two-line anchor installation technique.

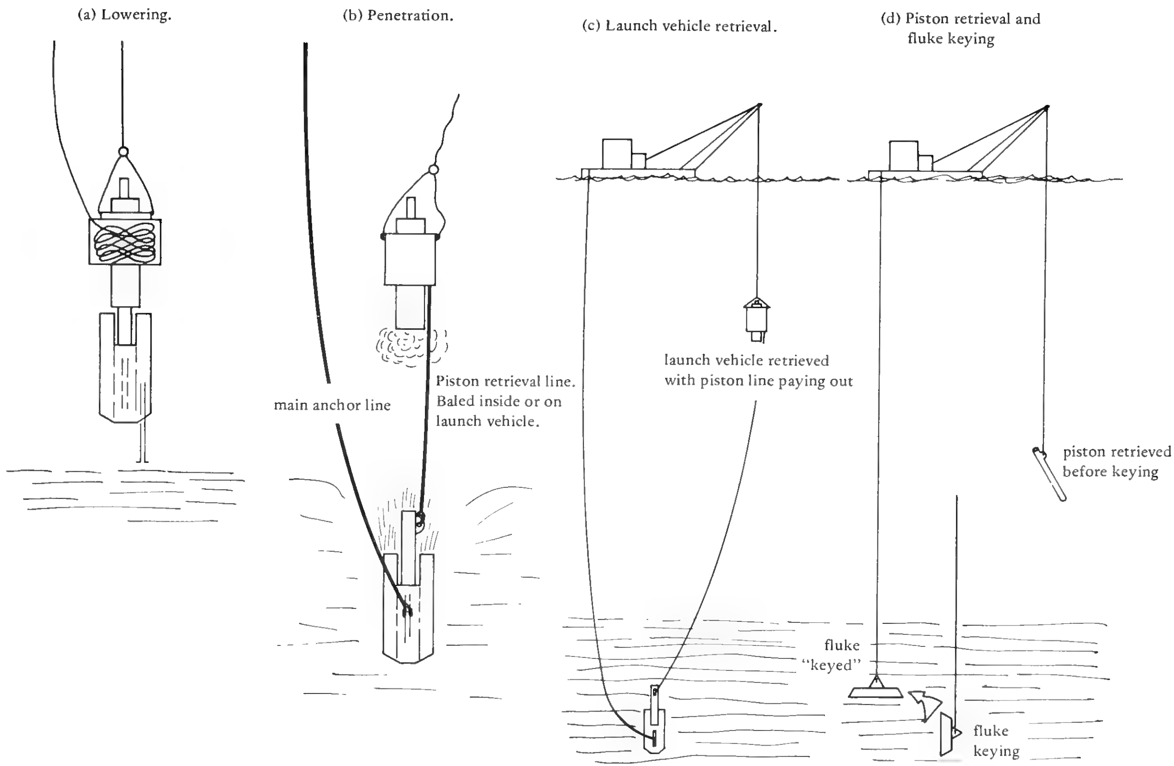


Figure B-3. Shallow-water, piston-retrieval technique.

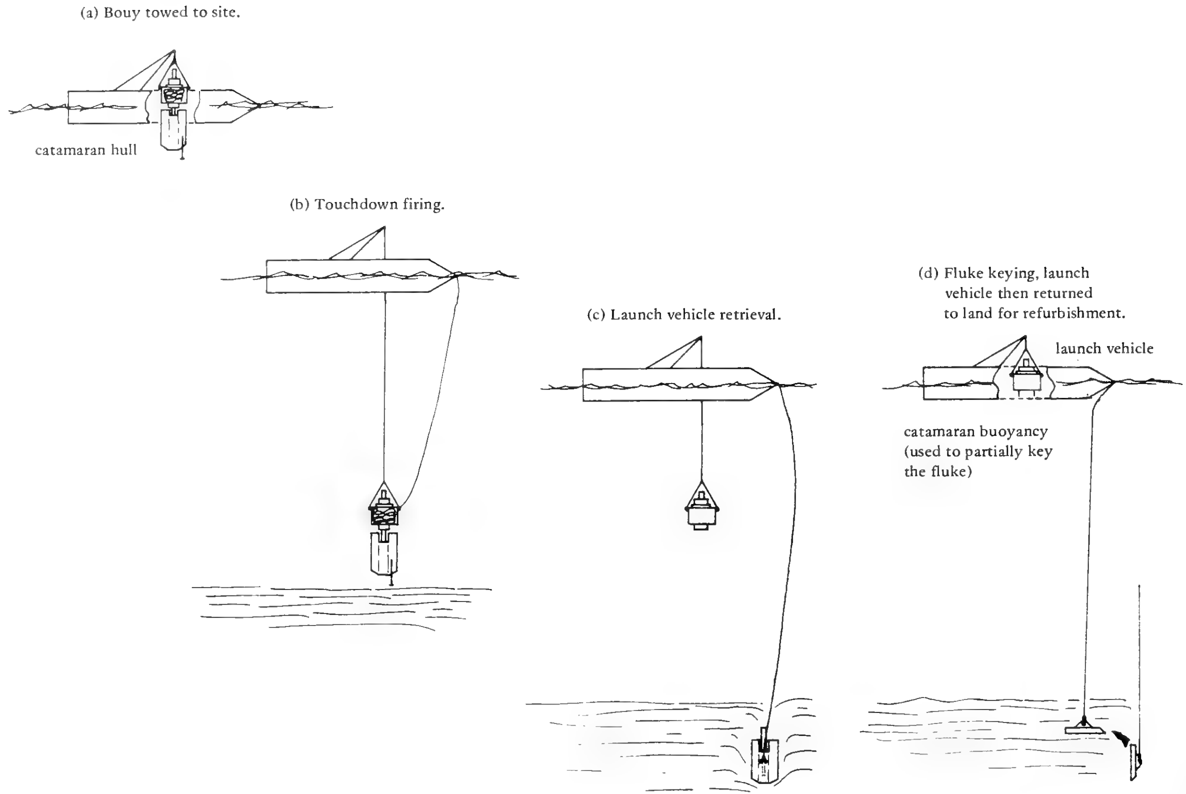


Figure B-4. Shallow-water, buoy-launched, deep-water anchor. (General idea from Reference 10)

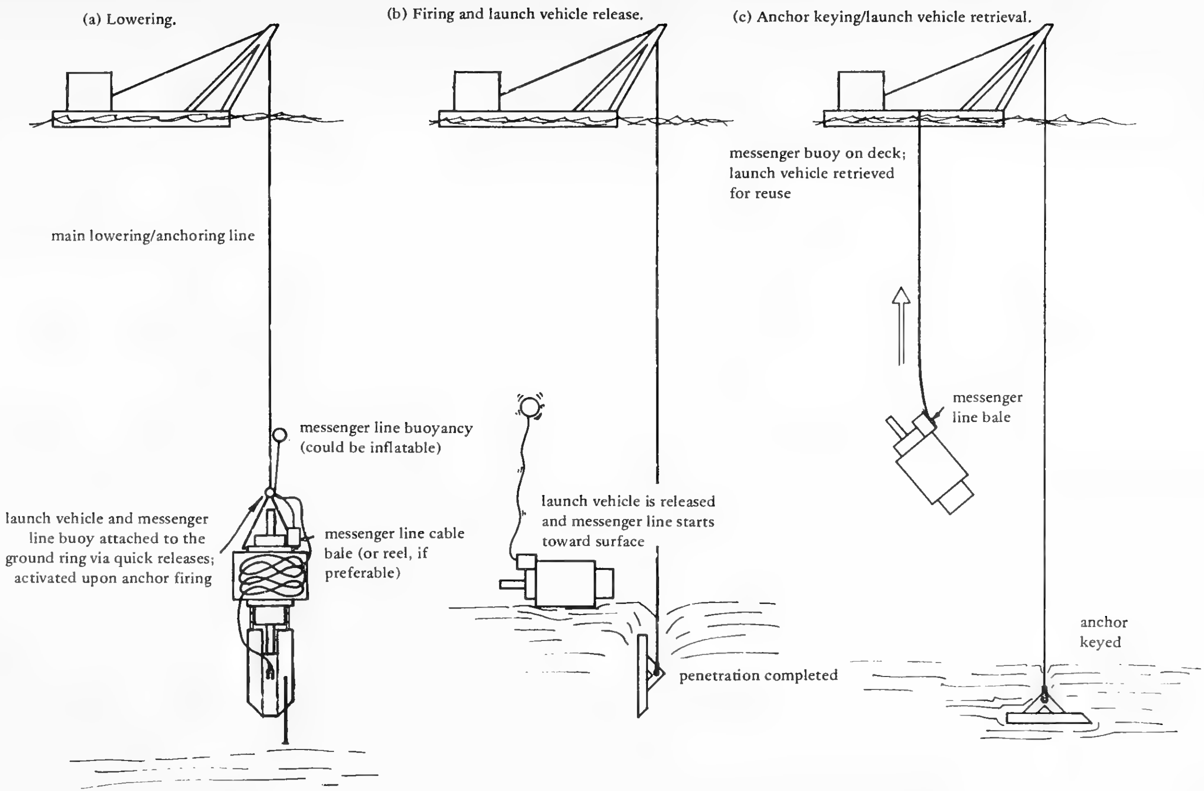


Figure B-5. Retrieval technique with gun assembly messenger line at moderate depths (<3,000 feet).

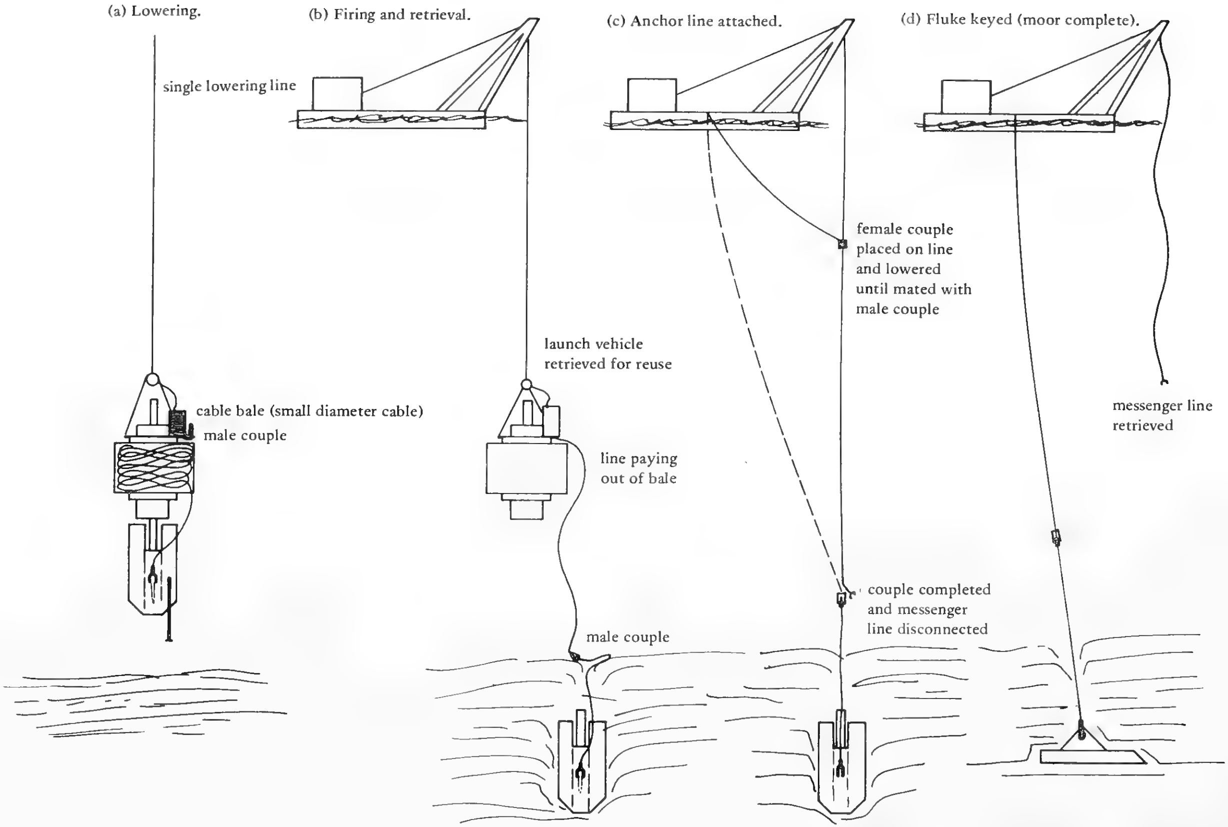


Figure B-6. Retrieval technique with anchor messenger line at moderate depths (<3,000 feet).

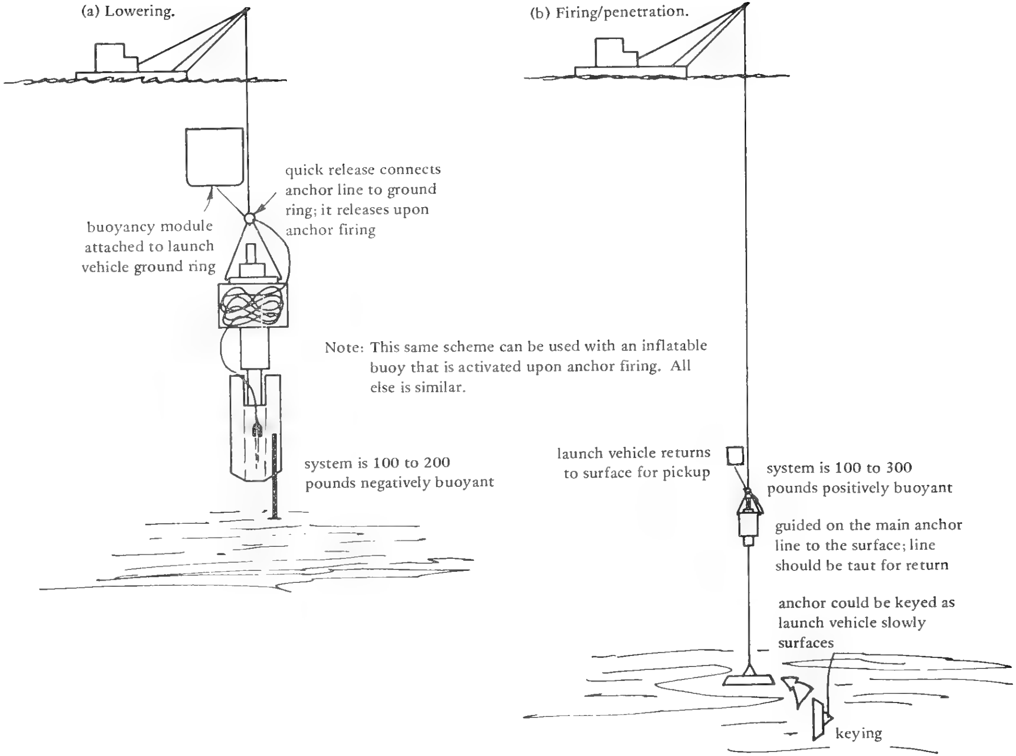


Figure B-7. Recovery technique for deep-water "Boomerang Anchor."

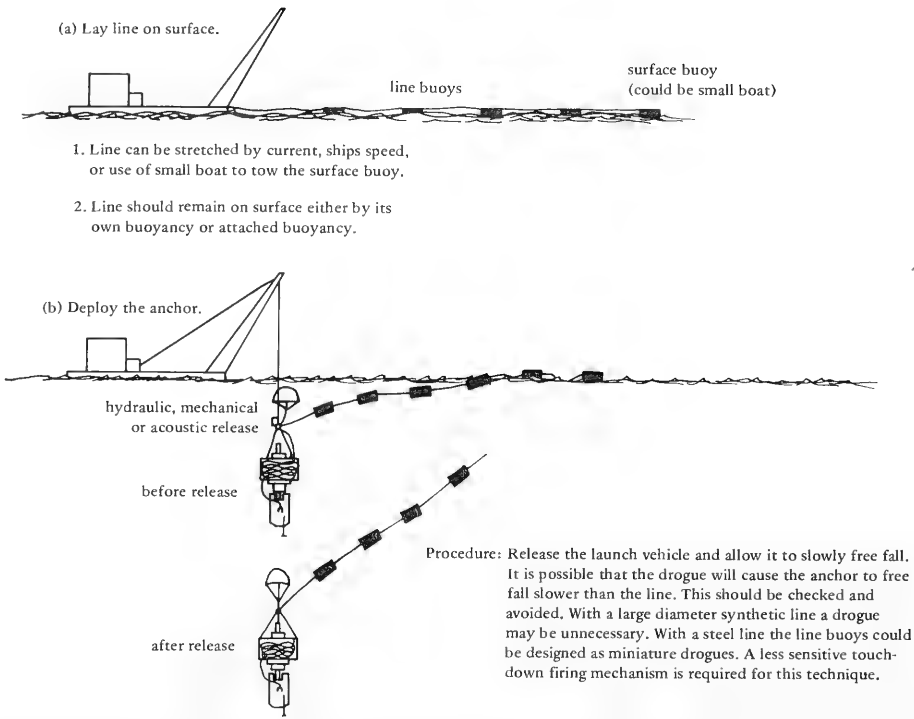


Figure B-8. Installation technique for Drogue free-fall anchor in deep water (<20,000 feet).

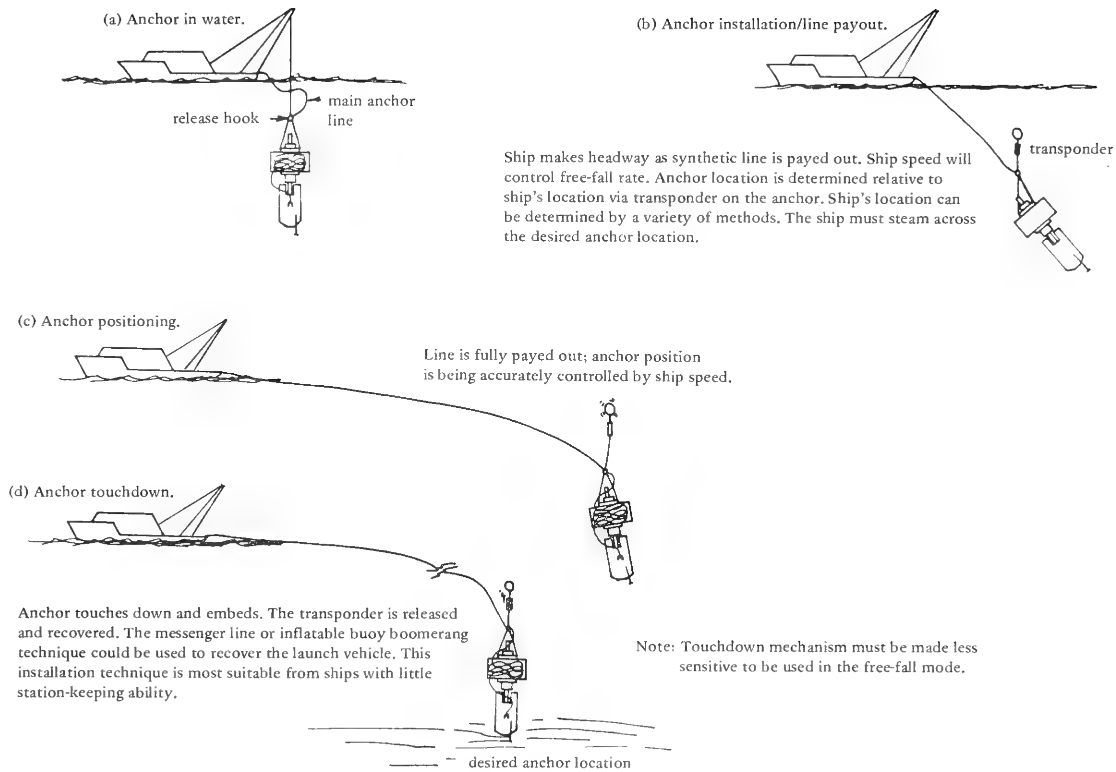


Figure B-9. Installation method for flown-in anchor in deep water.

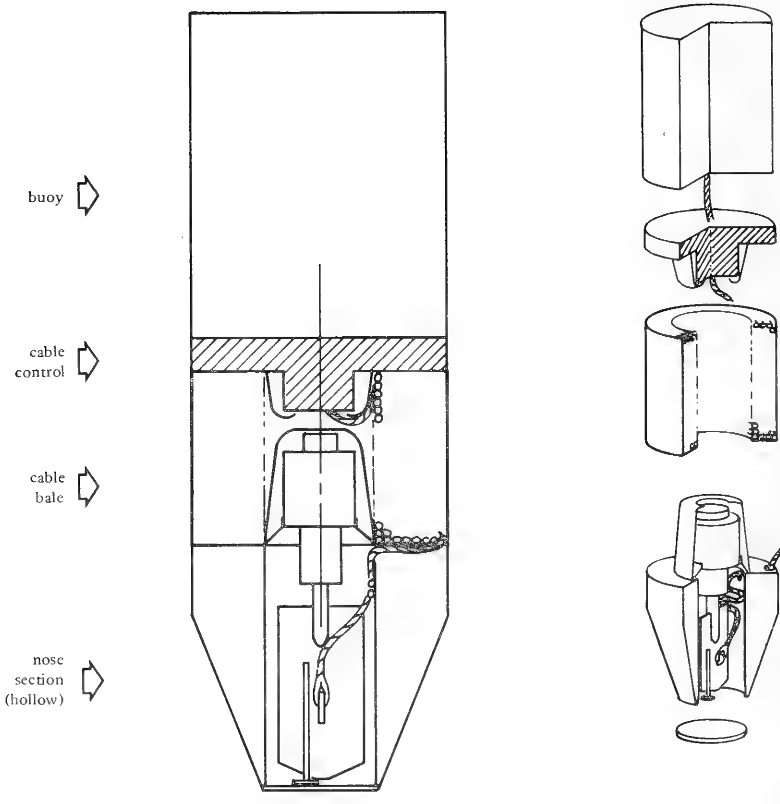


Figure B-10. Standard expedient mooring system package (from Reference 12).

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